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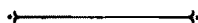
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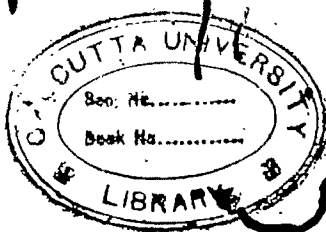
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AMERICAN JOURNAL OF SCIENCE

JULY 1928

A NEW GRAPTOLITE FAUNA FROM THE NIAGARAN OF NORTHERN INDIANA.

ROBERT R. SHROCK.

INTRODUCTION.

It is the purpose of this paper to describe a hitherto unknown graptolite fauna from one of the Niagaran formations of northern Indiana. This fauna was discovered and collected by Prof. E. R. Cumings and the writer during the summers of 1925-1927.*

So far as the writer has been able to learn from the literature, there have been reported but three species of graptolites from the Indiana Niagaran. In 1882 Hall¹ reported *Inocaulis divaricatus* and *Dendrograptus* (*Chaunograptus*) *novellus* from the Waldron shale of southern Indiana. In 1892 Eldrod and Benedict² gave a list of the fossils found in Wabash County, among which is a *Dictyonema* (?) sp. They state that all the fossils listed were found in the quarry stone, which is the Liston Creek limestone. It is quite possible, however, that this particular species came from the underlying Mississinewa shale, for the graptolites occur in the latter formation. In 1927 Cumings and Shrock³ mentioned a graptolite (*Dictyonema*) fauna from near Yorktown, Indiana, in the Mississinewa shale.

*A joint paper by Prof. Cumings and the writer, which will be published in the Bulletin of the Geological Society of America for 1928, gives the details of the stratigraphic sequence in which the Mississinewa shale is included, and of the enclosed reefs.

¹Hall, James, 11th Ann. Rept., Ind. Dept. Geol. and Nat. Hist. 225, pl. 1, Figs. 1-3, 1882.

²Eldrod, M. N., and Benedict, A. C., Geology of Wabash County, 17th Ann. Rept., Ind. Dept. Geol. and Nat. Res., 198-199, 1892.

³Cumings, E. R., and Shrock, R. R., The Silurian Coral Reefs of Northern Indiana and Their Associated Strata, Ind. Acad. Sci. Proc. for 1926, 73, 1927.

R. R. Shrock—New Graptolite Fauna.

HABITAT AND FAUNAL RELATIONSHIPS.

The Mississinewa shale, in which this interesting graptolite fauna is found, is a drab to bluish-gray calcareous shale (calclutite) or argillaceous limestone. The following analysis will indicate its chemical composition:

Moisture	0.82
Calcium carbonate	31.41
Magnesium carbonate	19.91
Silica	31.04
Ferrous oxide	3.04
Alumina	12.86
Titanium dioxide	0.50
Total	99.58

Enclosed in the upper eighty feet of this formation are numerous coral and stromatopora-like reefs, which are characterized by faunas distinctly different from that of the enclosing shale. The shale represents the calcareous muds deposited in the inter-reef areas. It was derived partly from the terrestrial silt brought in by rivers and currents from the nearby land, and partly from the main reef masses, parts of which were pulverized by the waves. Where it was being deposited the corals and other reef-building organisms could not flourish, but the graptolites, crustaceans and cephalopods found this habitat much to their liking.

In the sea in which the graptolites were growing there were the large reef mounds teeming with animal life made up of corals, stromatopora-like, Bryozoa, brachiopods, crinoids and the like; while out in the inter-reef expanses, where muddy waters were always present, flourished the delicate graptolites, the large crustaceans and molluscs and the huge *Orthoceratites*. There were probably some currents between the reef mounds where these animals were living. The conditions were very similar to those described by Chamberlin,⁴ Ruedemann⁵ and Grabau⁶ in Wisconsin, New York and on the Island of Gotland respectively.

In almost every case the graptolites are closely associated with the reefs. They may occur near the periphery of the reef, or in shale lenses which wedge into or interfinger with

⁴ Chamberlin, T. C., *Geology of Wisconsin*, 183-185, 1883.

⁵ Ruedemann, R., *Some Silurian (Ontarian) Faunas of New York*, N. Y. State Museum, Bull. 265, 7-8, 1925.

⁶ Grabau, A. W., *Principles of Stratigraphy*, 422, 1924.

the inclined strata of the reef flank (see Fig. 1), but never in the reef itself. The fragmental condition of some of the specimens indicates that they may have been transported a short distance by wave or current action, but it is very unlikely that they were transported very far, for many of the rhabdosomes are nearly perfectly preserved and could not have been moved far from the place in which they grew.

The contrast between the faunas of the reef core, reef flank, and inter-reef expanse is marked. Sea conditions in each part were distinctly different, and hence the faunas, although contemporaneous, are also distinctly different. The fauna of the

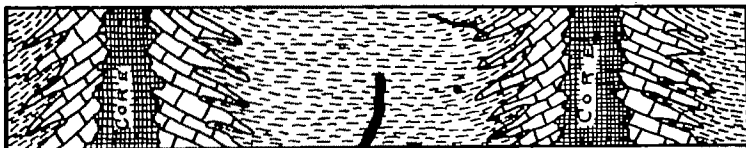


Fig. 1. Diagram showing the relationship of the Mississinewa shale to the inclined reef-flank strata, and to the reef core.

Mississinewa shale is dominantly a crustacean, orthoceratite and dendroid graptolite fauna; while the fauna of the contemporaneous reef is dominantly a stromatoporoid, coral, brachiopod and bryozoa fauna.

The following lists of fossils indicate the difference between the reef-flank and inter-reef faunas. The reef-core fauna may be considered as consisting essentially of the poorly preserved remains of stromatoporoids and corals.

*Quarry one-half mile east of Yorktown, Indiana, along
White River.*

Reef-flank strata:

- Anastrophia interplicata (Hall).
- Gypidula (Sieberella) galeata (Dalman).
- Pentamerus (?) oblongus Sowerby.
- Cladopora cf. laqueata Rominger.
- C. reticulata Hall.
- Favosites niagarensis Hall.
- Halysites catenularia (Linnaeus).
- Heliolites elegans Hall.
- H. interstinctus (Linnaeus).
- Stromatopora antiqua (Nicholson and Murie).

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R. R. Shrock—New Graptolite Fauna.

Bumastus armatus (?) (Hall).

B. insignis (Hall).

B. niagarensis (Whitfield).

Calymene cf. *vogdesi* Foerste.

Cheirurus niagarensis (Hall).

Dawsonoceras annulatum (Sowerby).

Phragmoceras angustum (Newell).

Protokionoceras crebescens (Hall).

P. medullare (Hall).

Protophragmoceras sp.

Mississippian shale:

Schizotreta tenuilamellata (Hall).

Spirifer (*Eospirifer*) *radiatus* (Sowerby).

Strophonella striata (Hall).

Dalmanites vigilans Hall.

Encrinurus indianensis Kindle and Breger.

Dawsonoceras annulatum (Sowerby).

Kionoceras cancellatum (Hall).

Orthoceras sp.

O. simulator Hall.

Protokionoceras sp.

P. medullare (?) (Hall).

Dendrograptus parallelus, n. sp.

D. praegracilis Spencer.

D. ramosus Spencer.

Callograptus pulchellus, n. sp.

C. pulchellus laxus, n. var.

C. niagarensis Spencer.

C. cf. strictus Gurley.

Dictyonema sp.

D. crassibasale Gurley.

D. filirapum Gurley.

D. lyriforme, n. sp.

D. percrassum Gurley.

D. polygonum, n. sp.

D. polymorphum Gurley.

D. polymorphum virgatum, n. var.

D. tenellum Spencer.

Desmograptus cumingsi, n. sp.

D. micronematodes (Spencer).

D. micronematodes magnus, n. var.

Thallograptus cervicornis (Spencer).

T. phycoides (Spencer).

Acanthograptus walkeri (Spencer).

Medusaegraptus (?) *mirabilis* Ruedemann.

Diplograptus (*Glyptograptus*) *niagarensis*, n. sp.

R. R. Shrock—New Graptolite Fauna.

Quarry one-half mile south of Markle, Indiana

Reef-flank strata:

- Atrypa reticularis (Linnaeus).
- Conchidium sp.
- C. littoni (Hall).
- C. multcostatum (Hall).
- Stricklandinia gaspiensis (Billings).
- Alveolites sp.
- Cladopora reticulata Hall.
- Eridophyllum rugosum Edwards and Haime.
- Favosites favosus (Goldfuss).
- F. niagarensis Hall.
- Halysites labyrinthicus (Goldfuss).
- Stromatopora antiqua (Nicholson and Murie).

Mississinewa shale lens:

- Dictyonema sp.
- D. filirum Gurley.
- D. parallelum Gurley.
- D. polymorphum Gurley.
- D. polymorphum virgatum, n. var.
- Desmograptus micronematodes (Spencer).
- Thallograptus cervicornis (Spencer).
- Inocaulis ramulosus Spencer.

DISTRIBUTION.

The distribution of the various species of graptolites is shown in the following faunal chart:

Faunal Chart.

Name of species	Y	W	M	L	K	D
Dendrograptus parallelus, n. sp.	x	..	..	..	..	..
D. praegracilis Spencer	x	..	..	..	..	..
D. ramosus Spencer	x	..	..	..	..	..
Callograptus niagaraensis	x	..	..	..	..	..
C. pulchellus, n. sp.	x	..	..	..	..	..
C. pulchellus laxus, n. var.	x	..	..	..	..	..
C. cf. strictus Gurley	x	..	..	..	..	..
Dictyonema sp.	x	x	x	x	x	..
D. crassibasale Gurley	x	..	..	..	..	..
D. filirum Gurley	x	..	x	x	..	..
D. lyriforme, n. sp.	x	..	..	..	..	..
D. parallelum Gurley	..	..	x	..	..	..
D. percrassum Gurley	x	..	..	..	..	..
D. polygonum, n. sp.	x	..	..	..	..	..
D. polymorphum Gurley	x	..	x	..	..	..
D. polymorphum virgatum, n. var.	x	..	x	..	..	..
D. tenellum Spencer	x	..	..	..	..	..
Desmograptus cumingsi, n. sp.	x	x	..	..	..	..

Name of species	Y	W	M	L	K	D
<i>D. micronematodes</i> (Spencer)	x	x	x	x	..	..
<i>D. micronematodes magnus</i> , n. var.	x	..	x	..	..	..
<i>Thallograptus cervicornis</i> (Spencer) ..	x	..	x	..	..	..
<i>T. phycoides</i> (Spencer)	x	..	..	..	..	..
<i>Inocaulis ramulosus</i> Spencer	..	x	x	..	..	..
<i>Acanthograptus walkeri</i> (Spencer)	x	..	..	..	..	..
<i>Medusaegraptus</i> (?) <i>mirabilis</i> Ruedemann ..	x	..	..	..	..	..
<i>Diplograptus</i> sp.	..	x	..	..	..	..
<i>D. (Glyptograptus) niagarensis</i> , n. sp.	x	..	..	..	..	..
<i>Monograptus falciformis</i> , n. sp.	..	..	..	..	..	x

Y—Quarry one-half mile east of Yorktown, Indiana, on the south bank of White River.

W—Wabash, Indiana.

M—Quarry one-half mile south of Markle, Indiana, on the east side of the highway.

L—Lagro, Indiana.

K—Markland Avenue quarry, Kokomo, Indiana.

D—Double Cliffs, near Red Bridge, Indiana, along the Mississinewa River in southwestern Wabash County.

It is seen that by far the majority of the forms were found in rock from the quarry one-half mile east of Yorktown, Indiana. Most of the specimens were collected from the large shale dump at the mineral wool factory just east of the town. Here an excellent opportunity was given to examine tons of the stone that had been hauled in from the quarry and left exposed to the weather through the winter months. The quarry from which the stone had been taken is located less than half a mile east of the wool factory on the south bank of White River. It is near the periphery of a large reef; for less than two hundred yards to the west, reef-flank strata are exposed in a second quarry where the reef collection listed above was obtained. At Markle the graptolites were found in some shaly material that had been excavated from a small quarry. The material appears to have formed a shale lens in the reef-flank strata which are exposed around the edge of the quarry. The specimens secured at Wabash, Lagro and Double Cliffs were also associated with reefs. At Kokomo, however, the shale is exposed in the bottom of a quarry and only over a limited area, so that nothing is known concerning the proximity of this exposure to a reef.

CORRELATION.

In the following faunal chart the graptolite fauna of the Mississinewa shale is compared with similar faunas from the base of the Lockport at Hamilton, Ontario; Gasport member

R. R. Shrock—New Graptolite Fauna.

of the Lockport limestone at Gasport and Lockport, New York; and Rochester shale of New York.

Faunal Chart.

Name of species	I	O	G	R
<i>Dendrograptus parallelus</i> , n. sp.	x	..	..	..
<i>D. praegracilis</i> Spencer	x	x	..	..
<i>D. ramosus</i> Spencer	x	x	..	..
<i>Callograptus niagarensis</i> Spencer	x	x	..	..
<i>C. pulchellus</i> , n. sp.	x	..	..	..
<i>C. pulchellus laxus</i> , n. var.	x	..	..	..
<i>C. cf. strictus</i> Gurley	x	x	..	..
<i>Dictyonema</i> sp.	x	..	..	..
<i>D. crassibasale</i> Gurley	x	x	x	..
<i>D. filiramus</i> Gurley	x	x	x	..
<i>D. lyriforme</i> , n. sp.	x	..	..	..
<i>D. parallelum</i> Gurley	x	x	..	..
<i>D. percrassum</i> Gurley	x	x	..	..
<i>D. polygonum</i> , n. sp.	x	..	..	..
<i>D. polymorphum</i> Gurley	x	x	..	x
<i>D. polymorphum virgatum</i> , n. var.	x	..	..	..
<i>D. tenellum</i> Spencer	x	x	x	..
<i>Desmograptus cumingsi</i> , n. sp.	x	..	..	..
<i>D. micronematodes</i> (Spencer)	x	x	x	..
<i>D. micronematodes magnus</i> , n. var.	x	..	..	..
<i>Thallograptus cervicornis</i> (Spencer)	x	x	..	..
<i>T. phycoides</i> (Spencer)	x	x	..	x
<i>Inocaulis ramulosus</i> Spencer	x	x	x	..
<i>Acanthograptus walkeri</i> (Spencer)	x	x	x	x
<i>Medusaegraptus</i> (?) <i>mirabilis</i> Ruedemann	x	..	x	..
<i>Diplograptus</i> sp.	x	..	..	..
<i>D. (Glyptograptus) niagarensis</i> , n. sp.	x	..	..	..
<i>Monograptus falciformis</i> , n. sp.	x	..	..	..

I—Mississinewa shale, Indiana.

O—Niagaran limestones, Hamilton, Ontario.

G—Gasport limestone, Gasport and Lockport, New York.

R—Rochester shale, New York.

Of the 16 described species found in Indiana, 15 are reported from Hamilton, Ontario; 7 from the Gasport limestone of New York; and 3 from the Rochester shale of New York. Seven species and 3 varieties are new; one *Dictyonema* and one *Diplograptus* (new) are not specifically identified; and *Medusaegraptus* is questionable.

Ruedemann⁷ considers the graptolite fauna of the Rochester shale of New York as essentially equivalent to the graptolite fauna found at Hamilton, Ontario. Bassler⁸ first considered

⁷ Ruedemann, R., Graptolites of New York, N. Y. State Museum, Memoir 11, pt. 2, 56, 1908.

⁸ Bassler, R. S., Dendroid graptolites of the Niagaran dolomites at Hamilton, Ontario, U. S. Nat. Mus., Bull. 65, 5, 1909.

the graptolite-bearing beds at Hamilton as Lockport in age, admitting the possibility of the lower beds of the section being of Rochester age, but later⁹ referred the graptolite fauna to the Rochester. Ruedemann¹⁰ recently described a number of graptolites from the Gasport member of the Lockport limestone of New York, which are of the same age as the fauna at Hamilton, Ontario.

Since the graptolite fauna of the Mississinewa shale agrees almost exactly with the graptolite fauna at Hamilton, Ontario, the two must be equivalent. In like manner, from the close agreement of the Gasport graptolites with those of the Hamilton formations, it would seem that the upper part of the Mississinewa shale, Gasport limestone, and the graptolite-bearing limestones and dolomites at Hamilton, Ontario, are of the same age. Judging from the position of the Gasport member, that age would have to be early Lockport. The presence of several typical Rochester forms, however, suggests the possibility that the Rochester shale may also be represented in the upper Mississinewa shale and in the basal beds of the Hamilton section. The upper Mississinewa shale is here considered of very late Rochester or very early Lockport age.

The finding of two *Diplograptidae* and a *Monograptus* again throws light upon the past connections of the Mississippi Basin with the European Province. The *Monograptus* has its nearest relatives in Europe, while the *Diptograptus* is close to several British Silurian forms.†

DESCRIPTION OF SPECIES.

Dendrograptus parallelus, n. sp.

Fig. 1a.

Description.—Although the left half of the frond is missing, yet the structure and size of this stately graptolite are beautifully shown in the specimen.

⁹ Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils, U. S. Nat. Mus., Bull. 92, 1489, 1915.

¹⁰ Ruedemann, R., Some Silurian (Ontarian) Faunas of New York, N. Y. State Museum, Bull. 65, 7-8, etc., 1925.

†Photographs of a number of the graptolites, including the *Monograptus* and *Diplograptus*, have been examined by Drs. Ruedemann and Bassler. Both were very kind in checking and correcting the identifications made by the writer, and he wishes to take this opportunity of thanking these eminent workers for their suggestions.

Three main branches, averaging 1 mm. in width, originate from a basal stipe 1.5 cm. long and slightly over 1 mm. in width, and by frequent bifurcation (about every 5 mm.), give rise to a very regular pattern. The branches show a strong tendency to run parallel to some other branch, giving rise to a dendritic pattern. The angle of bifurcation varies from 20° to 30° . From one main branch there arise ten branchlets by the time the distal portion of the frond is reached. The central branch seems to be more or less of an axis and gives off branchlets only in the distal portion.



Fig. 1a. *Dendrograptus parallelus*, n. sp. Camera drawing (natural size) of the type-specimen.

One centimeter below the junction of the three main branches the basal stipe bends abruptly, nearly at right angles, giving the appearance of a basal plate. The branches have corneous texture and appear to have been faintly striated longitudinally. No thecae are visible. No dissèpiments are present and the branches never join after bifurcation.

Dr. Ruedemann has suggested (personal communication) that this species may be nearer *Thallograptus* than *Dendrograptus*. In the absence, however, of well preserved material, the writer prefers to refer it to the latter genus. Its method of bifurcation and marked tendency of the branches to parallel each other give it an aspect different from any described form.

Horizon and locality.—Mississinewa shale from quarry one-half mile east of Yorktown, Indiana.

Dendrograptus praegracillis Spencer.

Fig. 9a.

Dendrograptus praegracilis Spencer, Canadian Nat., 10, 1882, p. 165 (nom. nud.); Trans. Acad. Sci. St. Louis, 4, 1884, p. 569, pl. 1, fig. 7; Bull. Mus. Univ. State Missouri, 1, 1884, p. 19, pl. 1, fig. 7.—Gurley, Jour. Geol., 4, 1896, pp. 95, 308.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, p. 9, pl. 2, fig. 3, text figs. 4, 10; Bull. U. S. Nat. Mus., 92, 1915, p. 400.

Description.—One nearly complete specimen of this beautiful slender graptolite was found in the quarry near Yorktown. The rhabdosome is 3 cm. high and 2 cm. broad. The main portion of the rhabdosome, which is slightly over 2 cm. high, originates from a long slender basal stipe, 0.9 mm. long and 0.2 mm. wide. Three main branches, by frequent bifurcation, give rise to numerous smaller branchlets in the distal portion. The main branches average 0.4 mm. in width, exceeding that figure somewhat just before bifurcation, while the smaller branchlets seldom reach 0.3 mm. in width. The distance between bifurcation varies from 1 mm. to over 3 mm. Small fragmentary branchlets are sometimes also given off from the main branches. The texture of the branches is corneous. The surface is covered with longitudinal striations. Dissepiments are not numerous and are far apart.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species is also found at Hamilton, Ontario, in the Niagaran limestones.

Dendrograptus ramosus Spencer.

Fig. 2.

Dendrograptus ramosus Spencer, Canadian Nat., 10, 1882, p. 165 (nom. nud.); Trans. Acad. Sci. St. Louis, 4, 1884, p. 567, pl. 1, fig. 3; Bull. Mus. Univ. State Missouri, 1, 1884, pp. 14, 17, pl. 1, fig. 3, 3a.—Gurley, Jour. Geol., 4, 1896, pp. 95, 308.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, p. 8, pl. 1, fig. 3; text figs. 3, 9; Bull. U. S. Nat. Mus., 92, 1915, p. 400.

Description.—One poorly-preserved specimen representing this species was found at Yorktown. The specimen is 4 cm. across, 3 cm. high, and apparently represents the distal portion of a large rhabdosome. The main branches average slightly less than 1 mm. in width, while the smaller branchlets may be as narrow as 0.6 mm. Our form seems to have the branching or bifurcating habit a little better developed than Spencer's type as figured by Bassler (1909). Because of compression

of the specimen in the rock, there is some overlapping of branches, and the irregular pattern which the branches make is undoubtedly due to the same cause. Dissepiments are rare, and when present are narrow. The right half of the frond (Fig. 2) is probably more characteristic of the true specimen.



Fig. 2. *Dendrograptus ramosus* Spencer. Camera drawing of several overlapping branches (natural size) from Yorktown, Indiana.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species is also found in the Niagaran limestones at Hamilton, Ontario.

Callograptus niagarensis Spencer.

Callograptus niagarensis Spencer, Canadian Nat., n. s., 8, 1878, p. 463; Trans. Acad. Sci. St. Louis, 4, 1884, p. 571, pl. 1, fig. 9; Bull. Mus. Univ. State Missouri, 1, 1884, p. 21, fig. 9.—Miller, N. A. Geol. Pal., 1889, p. 175, fig. 144.—Gurley, Jour. Geol., 4, 1896, pp. 93, 308.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 13, 14, fig. 15; Bull. U. S. Nat. Mus. 92, 1915, p. 162.

Description.—One incomplete frond from Yorktown seems nearest to this species. It agrees fairly well with the description and figure of Bassler (1909, 13-14) in general structure and size of branches but does not seem to have been so large. From the size of our fragment, the entire frond was little over 30 mm. wide and 20 to 25 mm. high. There seems to have been no common axis, the branches originating from the basal portion of the frond, and spreading out bush-like into a semi-circular form by frequent bifurcation. The branches vary from 0.2 mm. to 0.4 mm. in width. Dissepiments are not common.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. Also found in the Niagaran limestones at Hamilton, Ontario.

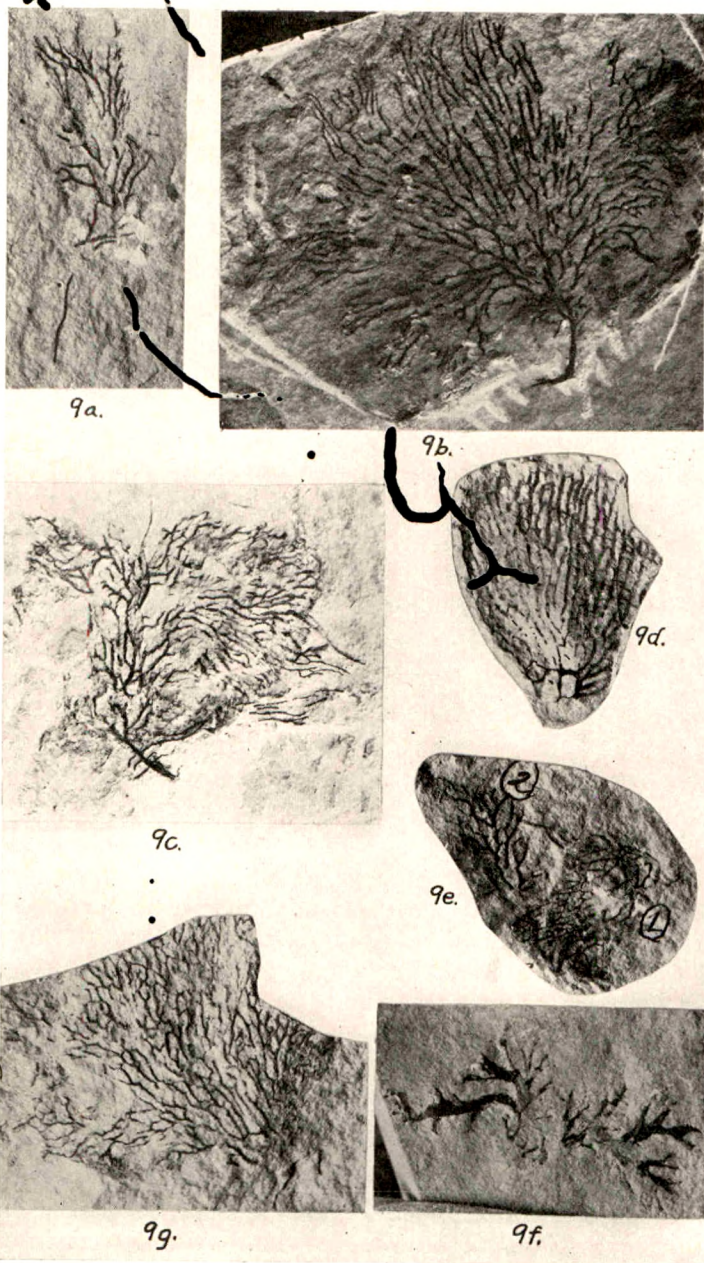


Fig. 9.

Callograptus pulchellus, n. sp.

Fig. 9b.

Description.—This beautiful graptolite is 45 mm. broad, 33 mm. high, and has a marked dendritic, or more correctly, bush-like habit. The main branches originate from a root-like basal stipe, and radiate outward, becoming more slender in the distal portion of the frond and usually ending in a two or three-pronged extremity. The root or basal stipe is about 8 mm. long, the proximal portion (3 mm.) of which may represent a basal disk. The branches average 0.45 mm. in width in the axial region and 0.25 mm. in the distal portion of the frond. The branches bifurcate quite frequently (every 2 to 3 mm.), are usually several times the width of a branch apart, and are occasionally joined by transverse dissepiments, which are almost always much narrower than the branches which they join. The dissepiments are usually far apart.

This species shows close resemblance to *C. niagarensis* Spencer, from which it may be distinguished by its marked bush-like or dendritic habit, its more regular and compact arrangement of branches, its basal root-like stipe and disk (?), and its greater number of dissepiments. This species also resembles *Dictyonema* somewhat, but has too lax a form, too frequent bifurcations, and hardly a sufficient number of dissepiments to be referred to that genus.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana.

Fig. 9.‡

- 9a. *Dendrograptus praegracilis* Spencer. Small rhabdosome, $\times 1.5$.
 9b. *Callograptus pulchellus*, new species. Type-specimen, $\times 1.5$.
 9c. *Callograptus pulchellus laxus*, new variety. Type-specimen, $\times 1.5$.
 9d. *Dictyonema lyriforme*, new species. Type-specimen, $\times 1.5$.
 9e. *Callograptus* cf. *strictus* Gurley. A fragmentary rhabdosome (2), $\times 1.5$. The specimen marked (1) is too fragmental for accurate determination. It is close to *Desmograptus micronematodes* (Spencer).
 9f. *Thallograptus cervicornis* (Spencer). A nearly complete specimen, $\times 1.5$. This is a rather small rhabdosome. (See Figs 11a and 11g.) Yorktown, Indiana.
 9g. *Dictyonema polymorphum* Gurley. The distal portion of a frond, $\times 1.5$. This specimen belongs to the larger forms of *polymorphum*. (See Figs. 10b, 10c and 10d.) Yorktown, Indiana.

‡ All photographs were made by Dr. E. R. Cumings and the writer.

Callograptus pulchellus laxus, n. var.

Fig. 9c.

Description.—The frond, which is 35 mm. broad and 25 mm. high, originates from a thick basal stipe slightly over 1 mm. in width and 4 mm. long. From the three or four main branches in the axial region are given off numerous branches which radiate outward bush-like and then droop downward at the distal extremity. From the position of these slender branches in the compressed specimen, it is quite likely that they were over 25 mm. in length, and extended outward from the main axial branches at nearly right angles. The main branches in the axial region average from 0.6 to 0.08 mm. in width, and the slender branchlets seldom exceed 0.25 mm. in width, being most slender in the distal portion of the frond. Bifurcation is very frequent, particularly near the axial region. Narrow dissepiments are quite common, and are usually transverse or very nearly so.

This specimen is very close to *C. pulchellus*, but has certain differences which justify its being made a variety of the above species. It may be distinguished from the type of the species by its more lax form, more variable thickness of branches, and more pronounced axial region. This variety, like *C. pulchellus*, is very close to *C. niagarensis* Spencer, but differs from that species in the absence of a thick, common axis, more compact arrangement of branches in the distal regions, and greater number of dissepiments.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana.

• *Callograptus cf. strictus* Gurley

Fig. 9e (2).

Callograptus strictus (Gurley MS) Bassler, Bull. U. S. Nat. Mus., 65, 1909, p. 15, fig. 17; pl. 3, fig. 3; Bull. U. S. Nat. Mus., 92, 1915, p. 162.

Description.—An incomplete rhabdosome, found in the quarry near Yorktown, agrees best with this species as figured by Bassler (1909, fig. 17, p. 15). It is a somewhat more delicate form, the branches seldom reaching 0.5 mm. in width and averaging about 0.3 mm. in width. The branches bifurcate at intervals of from 1 to 3 mm. Several dissepiments are present, although they are not common.

Horizon and locality.—Mississinewa shale at quarry one-

half mile east of Yorktown, Indiana. This species is also found in the Niagaran limestones at Hamilton, Ontario.

Dictyonema, sp.

Numerous fragments of *Dictyonema*, too small for positive specific determination, were found in the Mississinewa shale at Markland Avenue quarry, Kokomo, Indiana; quarry one-half mile east of Yorktown, Indiana; road cut, S. Wabash, Indiana; and quarry one-half mile south of Markle, Indiana.

In these specimens there were too few branches and dissepiments to be sure about their size and arrangement. One specimen from Yorktown agreed fairly well with *D. desmoides* Gurley, but such an identification is doubtful at best.

Dictyonema crassibasale Gurley.

Dictyonema gracilis Spencer (not Hall), Canadian Nat., n. s., 8, 1878, p. 458; *ibid.*, 10, 1882, p. 165. Trans. Acad. Sci. St. Louis, 4, 1884, pp. 573, 574, pl. 2, figs. 2, 3; Bull. Mus. Univ. State Missouri, 1, 1884, p. 24, pl. 2, figs. 2, 2a, 3.

Dictyonema crassibasale (Gurley MS) Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 19-24, pl. 3, fig. 1; text figs. 21-25; Bull. U. S. Nat. Mus., 92, 1915, p. 422.—Ruedemann, Bull. N. Y. State Mus., 265, 1925, p. 22, pl. 1, fig. 1; text figs. 12, 13.

Description.—Four incomplete specimens of this graptolite were found at Yorktown. They agree fairly well with the descriptions given by Bassler (1909) and Ruedemann (1925).

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species has also been found in the Niagaran limestones and dolomites at Hamilton, Ontario, and in the Gasport member of the Lockport limestone at Gasport, and Lockport, New York.

Dictyonema filiramum Gurley

Figs. 11c, 11d.

Dictyonema filiramum (Gurley MS) Bassler, Bull. U. S. Nat. Mus., 65, 1909, p. 34, figs. 38-40; Bull. U. S. Nat. Mus., 92, 1915, p. 423.—Ruedemann, Bull. N. Y. State Mus., 265, 1925, pp. 7, 24, text fig. 15.

Description.—This species seems to be quite common at Yorktown, where six incomplete specimens were found. One specimen was found at "The Narrows" near Lagro, and another from near Markle seems to agree best with this species. Owing to the fragmentary character of the specimens nothing can be added to the description given by Bassler (1909). The branches in our specimens seem to be rather heavy.

R.

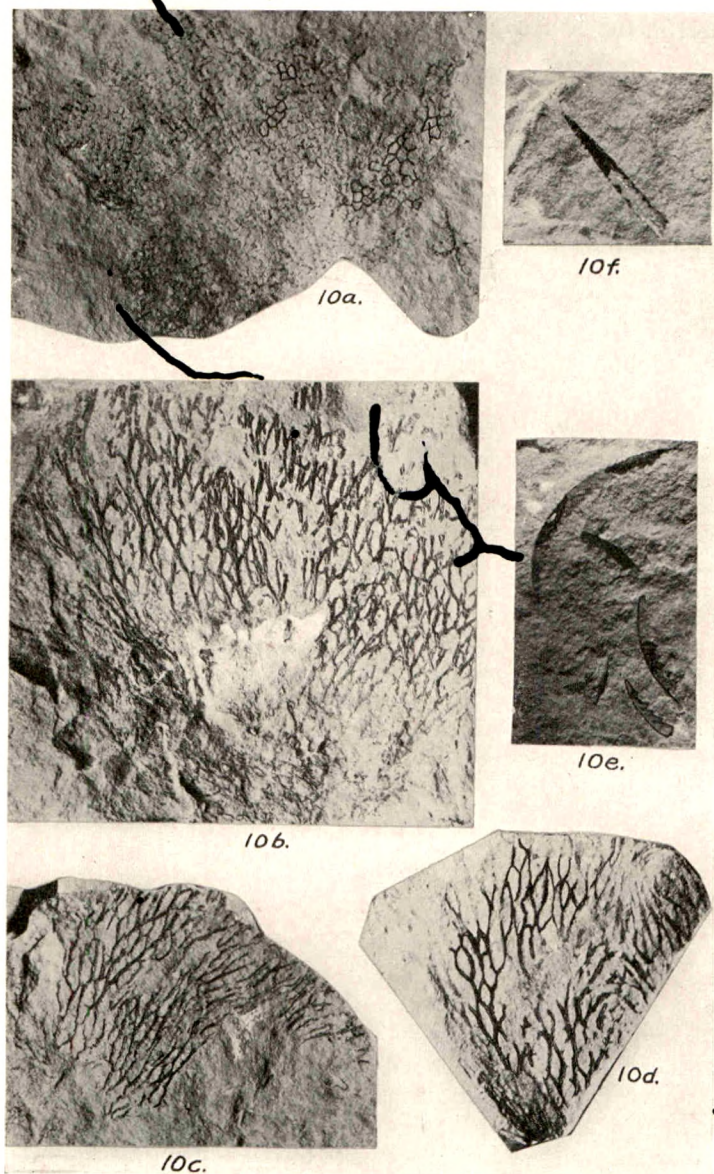


Fig. 10.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown; at "The Narrows," one mile south of Lagro; and at quarry one-half mile south of Markle. This species has also been reported from the Niagaran dolomites at Hamilton, Ontario, and from the Gasport member of the Lockport limestone at Gasport, New York.

Dictyonema lyriforme, n. sp.

Fig. 9d.

Description.—This stately little graptolite was found in the Mississinewa shale near Yorktown, Indiana. The frond measures 18 mm. across the distal portion and 21 mm. in height. The branches average 0.5 mm. in width throughout and vary but little from that figure. They are joined by numerous transverse dissepiments which are regularly 1 mm. apart. The dissepiments average 0.2 mm. in width and occur more numerous in the distal portion of the frond. The branches are usually separated by a distance equal to or greater than their width.

The frond is more or less cup-shaped. The branches seem to originate from a basal stipe, although there is some uncertainty about this, due to poor preservation of the proximal region. The branches seldom bifurcate more than twice between the base of the frond and the distal extremity. There are 24 branches distally in a distance of 18 mm., while there are not over 12 in the same distance proximally. Bifurcations are U-shaped.

This species agrees fairly well with *Odontocaulis obpyriformis* Gurley, but may be distinguished from it by the greater number and thickness of the branches, greater number of dissepiments, large size of rhabdosome, and absence of thecate

Fig. 10.

10a. *Dictyonema polygonum*, new species. Type-specimen, x 1.5.

10b, 10c, 10d. *Dictyonema polymorphum* Gurley. Yorktown, Indiana. b, A fragment, x 1.5, showing some details of the branches. c, Distal portion of a frond, x 1.5, showing predominance of transverse dissepiments. d, Proximal portion of a frond, x 1.5, showing the predominance of *Desmograptus* structure. The branches are somewhat larger than in Fig. 10c.

10e. *Monograptus falciformis*, new species. Type-specimen, x 1.5. (See Figs. 7 and 8.)

10f. *Diplograptus* (*Glyptograptus*) *niagarensis*, new species. Type-specimen, x 1.5 (See Fig. 6.)

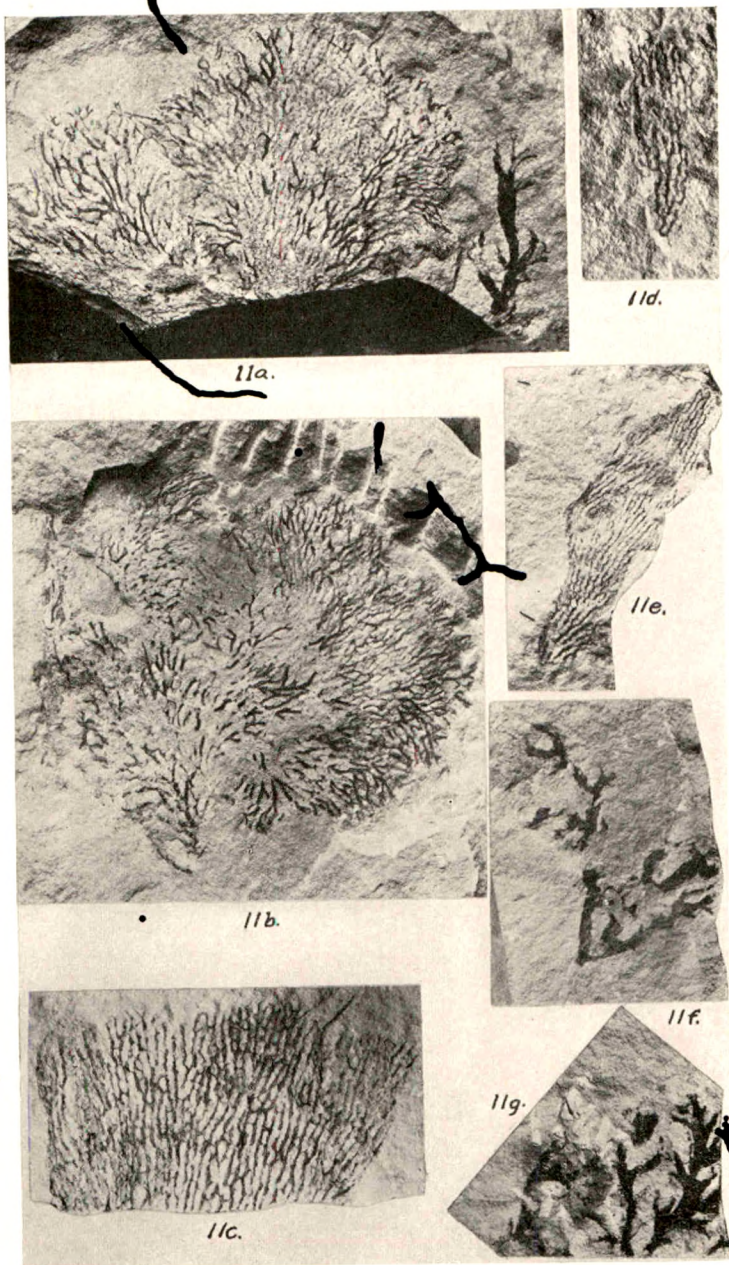


Fig. 11.

stem. Even if our specimen should possess a thecate stem, it would still be nearer the genus *Dictyonema* than *Odontocaulis*. Bassler (1909, p. 42), in discussing the description of the *Odontocaulis*, states that Gurley has based the genus chiefly on the presence of a single thecate stem, from which the entire rhabdosome originates, and the presence of dissepiments in the distal portion. Since the presence of such a stem is doubtful in our specimen, and also since the dissepiments are so numerous, it is deemed best to refer this specimen to the genus *Dictyonema*.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana.

Dictyonema parallelum Gurley.

Fig. 12b.

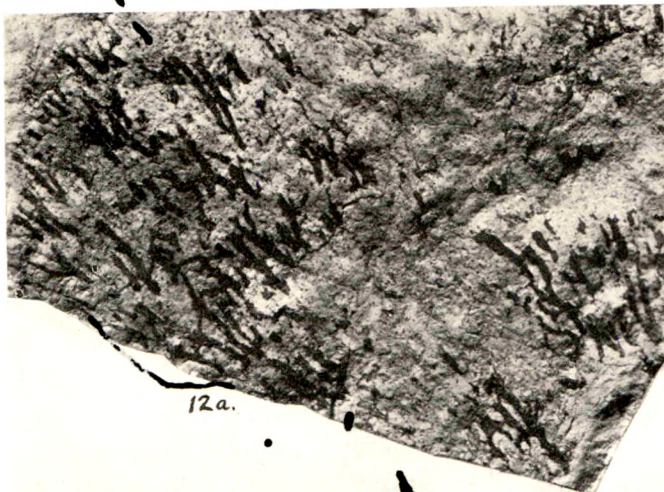
Dictyonema parallelum (Gurley MS) Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 37, 38, pl. 4, fig. 2, text fig. 47; Bull. U. S. Nat. Mus., 92, 1915, p. 425.

Description.—One good specimen representing this species was found near Markle. To the description given by Bassler (1909, p. 37) the following may be added:

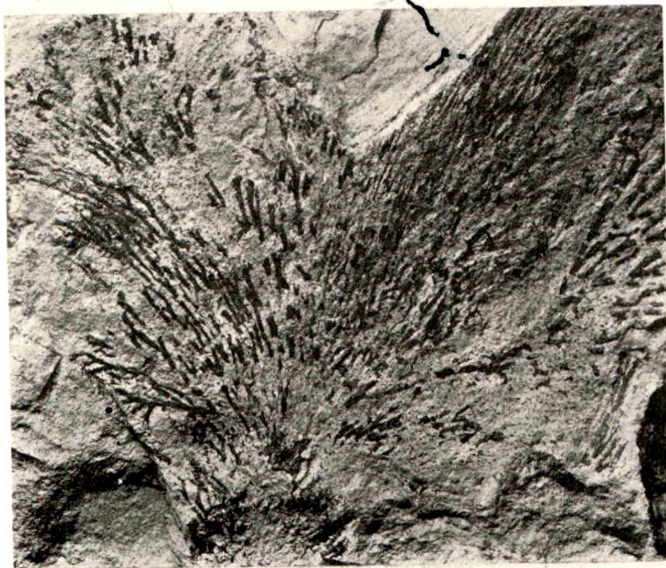
Our specimen is 70 mm. wide and over 60 mm. high. The proximal portion of the frond is missing. The branches diverge rather rapidly from the base radially outward, giving the frond the appearance of a fan, the branches representing the ribs of the fan. Transverse dissepiments are common, occurring from 2.5 to 3 mm. apart. In some cases the branches appear to anastomose. They have corneous texture and are longitudinally striated. Their width may swell to almost 1 mm. or may decrease to less than 0.4 mm. They

Fig. 11.

- 11a, 11b. *Dictyonema polymorphum virgatum*, new variety. From Yorktown, Indiana. 11a. Larger specimen, x 1.5, and a stipe of *Thallograptus cervicornis* (Spencer). 11b. Type-specimen, x 1.5, showing the shape, general structure, and size and number of the branches.
 11c, 11d. *Dictyonema filiramum* Gurley. From Yorktown, Indiana. c, Incomplete specimen (distal portion), x 1.5; d, A fragmental frond, x 1.5.
 11e. *Dictyonema tenellum* Spencer. A nearly complete specimen, x 1.5.
 11f. *Thallograptus phycoides* (Spencer). Distal portion of a frond, x 1.5, from Yorktown, Indiana.
 11g. *Thallograptus cervicornis* (Spencer). Several stipes, x 1.5, from Yorktown, Indiana. (See Figs. 9f and 11a.)



12a.



12b.

Fig. 12.

- 12a. *Dictyonema percrassum* Gurley. Distal portion of a large frond, x 1.5.
 12b. *Dictyonema parallelum* Gurley. A nearly complete specimen, x 1.5.

are wider proximally or just before bifurcation. The thecae are arranged 3 to 4 in 1 mm. Bifurcation is frequent in some parts of the frond and infrequent in others. One branch may not bifurcate within 1 cm. while a second may bifurcate four times in that distance.

Horizon and locality.—Mississinewa shale at quarry one-half mile south of Markle, Indiana. This species is also found at Hamilton, Ontario, in the Niagaran dolomites.

Dictyonema percrassum, Gurley.

Fig. 12a.

Dictyonema percrassum (Gurley MS) Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 35, 36, figs. 44, 45; Bull. U. S. Nat. Mus., 62, 1915, p. 425.

Description.—An incomplete specimen, representing the distal portion of a large frond, was found at Yorktown. To Bassler's description (1909, pp. 35-36) the following may be added:

Our incomplete specimen measures 10 cm. in width and 7 cm. in height, indicating that the entire frond must have been several times larger at least. The branches diverge somewhat, and are characterized by corneous texture and striated surfaces. They average about 1 mm. in width, often swelling to 1.4 mm. just before bifurcating, and decreasing to 0.6-0.8 mm. immediately after bifurcation. Dissepiments are quite numerous, occurring from 2 to 3.5 mm. apart. They are seldom as close as 1 mm. Interspaces between branches are equal to or less than the width of the branches, never greater. Occasionally there are V-shaped dissepiments, with the apex of the V toward the distal extremity, formed by the junction of two oblique dissepiments. Usually, however, the dissepiments are transverse and average 0.2 mm. in width, rarely swelling to over 0.5 mm. Numerous fragmentary dissepiments or branchlets frequently occur along the sides of the main branches, but they do not join as true dissepiments.

The thecae are visible as circular elevations of corneous material, where the branch has been exfoliated, or as circular depressions, where the corneous material is absent, indicating that they projected above the general surface of the branch. They occur consistently about 0.5 mm. apart, although in some parts of the frond there may be as many as 4 in 1 mm.

Our specimen seems to be a somewhat more massive form than those figured by Bassler (1909), but the general structure is very similar.

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Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species has also been reported from the Niagaran dolomites at Hamilton, Ontario.

Dictyonema polygonum, n. sp.

Fig. 10a.

Description.—An incomplete frond from the Mississinewa shale at Yorktown shows some very interesting characteristics. The branches are more or less parallel like *Dictyonema*. Transverse, or nearly transverse, dissepiments are numerous, but the meshes are polygonal in shape, instead of square or rectangular, and the branches are very slender, almost never exceeding 0.25 mm. in width and more often much more slender. The meshes average slightly less than 1 mm. across, although many are much smaller.

Our frond is 35 mm. broad and 28 mm. high, with the proximal portion missing. It resembles the distal portion of Ruedemann's (1925, p. 21) Fig. 7 of *Desmograptus micro-nematodes* (Spencer), but has smaller meshes and better developed *Dictyonema* structure. Upon the suggestion of Dr. Ruedemann (personal communication), this specimen is referred to *Dictyonema* rather than to *Desmograptus*. It seems to represent a transitional form between these two genera, partaking of some of the characteristics of both.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana.

Dictyonema polymorphum Gurley.

Figs. 9g, 10b, 10c, 10d.

Dictyonema tenellum Spencer, Trans. Acad. Sci. St. Louis, 4, 1884, pl. 1, fig. 13 (not description, p. 576); Bull. Mus. Univ. State Missouri, 1, 1884, pl. 1, fig. 13 (not description, p. 26).

Calyptograptus subretiformis Spencer (part), Trans. Acad. Sci. St. Louis, 4, 1884, pl. 4, fig. 2; Bull. Mus. Univ. State Missouri, 1, 1884, pl. 4, fig. 2.

Dictyonema polymorphum (Gurley MS) Ruedemann, Mem. N. Y. State Mus., 11, 1908, p. 158, pl. 2, fig. 3; pl. 3, figs. 4, 5, 6; p. 160, figs. 60-72.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, p. 24, pl. 4, fig. 11; U. S. Nat. Mus., 92, 1915, pp. 425-426.

Description.—This species is by far the most abundant graptolite in the Mississinewa shale. From a study of the numerous specimens in our collection, it appears that this species has been made a receptacle for several distinct varieties, if not species.

An elaborate description of this species is given by Ruedemann (1908, pp. 158-162) and repeated by Bassler (1909, pp. 24-26). In our collection, which includes some forty or more specimens, most of which are fragments or incomplete rhabdosomes, all the diverse forms mentioned by these two authorities are found along with several other interesting ones.

A number of our specimens are characterized by very slender branches which are usually about 0.25 mm. wide and seldom over 0.4 mm. These forms have fewer dissepiments and more anastomosing of the branches than the normal *polymorphum*, but because of similar structure seem to be nearer to *D. polymorphum*, of which they very likely form a variety. They are hardly close enough to *Desmograptus* to be referred to that genus.

Other specimens, however, have thicker branches and agree very closely with the figures given by Ruedemann and Bassler. Within the same specimen the branches may vary from 0.25 mm. to 0.6 mm. in width, and may anastomose, or be joined by transverse or oblique (45°) dissepiments. The meshes may be irregular, diamond-shaped, elliptical or oblong, depending on the way in which the branches join. The general structure as a whole in almost all of the specimens seems to be nearer *Desmograptus* than *Dictyonema*, but there are certain specimens which seem to be transitional between these two genera. More will be said concerning this species under *Desmograptus micronematodes* (Spencer).

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana; and at quarry one-half mile south of Markle, Indiana. The species has also been described from the Niagaran dolomites at Hamilton, Ontario, and from the Rochester shale at Middleport, New York.

Dictyonema polymorphum virgatum, n. var.

Figs. 11a, 11b.

Description.—Two specimens from Yorktown and one from Markle show a very interesting variation from *D. polymorphum*. The fronds are bush-like in form, with the branches originating from the base and radiating rather rapidly outward, forming a more or less circular frond. The branches become more slender in the distal portion and droop somewhat.

The branches vary from 0.25 to 0.5 mm. in width. They are joined by anastomosis, or by dissepiments which may be either transverse or oblique. The dissepiments are usually 0.2 mm. or less in width and are very numerous. These specimens show close resemblance to *Desmograptus* in the distal portion.

The branches are corneous and striated, and rarely extend over 2.5 mm. before anastomosing or joining with each other by dissepiments. The meshes show considerable variation in shape. They may be polygonal, oblong, irregular or rectangular. Our specimens show widths of 40 mm. and heights of 24 and 35 mm.

This form is distinctive, and although very close to *D. polymorphum* Gurley, certainly represents either a variety of that species, or else an entirely new species. Here again is a form which has characteristics of both *Dictyonema* and *Desmograptus*, and appears to be transitional between the two genera.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana; and at quarry one-half mile south of Markle, Indiana.

Dictyonema tenellum Spencer.

Fig. 11e.

Dictyonema tenellum Spencer, Canadian Nat., n. s., 8, 1878, pp. 458, 459; ibid., 10, 1882, p. 165; Trans. Acad. Sci. St. Louis, 4, 1884, pp. 564, 576 (not pl. 1, fig. 13); Bull. Mus. Univ. State Missouri, 1, 1884, pp. 14, 26 (not pl. 1, fig. 13).—Miller, N. A. Geol. Pal., 1889, p. 185.—Gurley, Jour. Geol., 4, 1896, pp. 96, 308.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 28-30, pl. 2, fig. 4, text figs. 32, 33; Bull. U. S. Nat. Mus., 92, 1915, p. 427.—Ruedemann, Bull. N. Y. State Mus., 265, 1925, pp. 26, 27, text figs. 17, 18.

Description.—Little can be added to the descriptions given by Bassler (1909). Our specimen is 28 mm. long and 10 mm. wide at its greatest width. Bifurcations are rare, and usually occur near the proximal extremity. The branches, which appear to originate from a single stipe, extend the full length of the frond with but three or four bifurcations. The meshes are sometimes almost circular in outline.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species is also found in the Niagaran dolomites at Hamilton, Ontario, and in the Gasport member of the Lockport limestone at Lockport, New York.

Desmograptus cumingsi, n. sp.

Fig. 13a.

Description.—This beautiful frond, which is 3 cm. wide and 4.2 cm. high, originates from a single basal stipe, 1 cm. long and 0.7 mm. broad. Near the end of the stipe there is a fragmental root which may have been a brace root.

The structure of the frond is typically that of *Desmograptus*. The branches, which vary from 0.3 to 0.5 mm. in width, anastomose or join by means of transverse or oblique dissepiments, and give rise to a rather regular pattern composed of biconvex meshes from 1.5 to 3 mm. long and 1 mm. or less wide. The dissepiments are 0.2 mm. wide, and are almost always oblique. There is some overlapping of branches. The branches have corneous texture and are longitudinally striated, although the latter feature is not well shown in the specimen.

This species is close to *Dictyonema subretiforme* (Spencer) but is more delicate and has few transverse dissepiments. Its structure, however, is much nearer *Desmograptus* than *Dictyonema*, according to Dr. Ruedemann (personal communication), and is, therefore, referred to that genus.

This species is named in honor of Prof. E. R. Cumings who, for a number of years, has been a constant inspiration to the writer in his paleontologic and stratigraphic work.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana, and in the road cut at Wabash, Indiana.

Desmograptus micronematodes (Spencer?)

Fig. 13c.

Calyptragraptus micronematodes Spencer, Canadian Nat., 10, 1882, p. 165 (nom. nud.); Trans. Acad. Sci. St. Louis, 4, 1884, pp. 564, 579, 588, pl. 3, fig. 4, 4a; Bull. Mus. Univ. State Missouri, 1, 1884, pp. 14, 29, 38, pl. 3, fig. 4, 4a.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 39-40, figs. 49, 50; Bull. U. S. Nat. Mus., 92, 1915, p. 170.

Calyptragraptus micronematodes Gurley, Jour. Geol., 4, 1896, pp. 93, 308.
Desmograptus micronematodes Ruedemann, Bull. N. Y. State Mus., 265, 1927, pp. 21, 22, text figs. 7-11.

Description.—This species is the second most abundant graptolite in the Mississinewa shale. It shows considerable variation in shape, size and pattern or structure. As stated by Ruedemann (1925, p. 22) both *Desmograptus* and *Dictyonema* structure frequently occur in the same specimen. The

GROUP No. 1. In this group are included a number of specimens very close to *D. micronematodes magnus*, n. var., except in the shape and size of the fronds, and the regularity of the structure. The size of the branches is essentially the same. The measurements for three fronds will indicate how nearly parallel the sides of the fronds are.

"	40	"	38	"	28	"	"
"	8	"	5	"	7	"	"

Nine specimens were found in the Mississinewa shale from the quarry one-half mile east of Yorktown, Indiana.

GROUP No. 3. A number of forms found at Yorktown and Markle are transitional between *Dictyonema polymorphum* and *Desmograptus micronematodes*. The branches are slender, averaging between .025 and 0.3 mm. in width. The structure is quite lax, instead of compact as in the latter or

regular as in the former. The branches not only anastomose, but also join by means of both transverse and oblique dissepiments. These specimens most nearly compare with Bassler's fig. 50 (1909, p. 40), but are much more lax, and Ruedemann's fig. 11 (1925, p. 21), which is much smaller than our specimens. The dissepiments are mostly oblique, forming meshes which vary from 1.2 to 3 mm. in length, and which are 1 mm. or more in width. These meshes are often quite irregular. The thecae appear as circular rings of corneous material. They average 2 to 3 in 1 mm. With such a great diversity in the size of the meshes, it raises the question as to whether all these forms should be included under *micronematodes*.

One form from Yorktown is very close to what Bassler (1909, p. 41, Fig. 52) has called *Rhizograptus bulbosus* except for the absence of a bulbous root. There seems to be no difference between this particular specimen and several others that most certainly are referable to *Desmograptus*. With sufficient material *R. bulbosus* may turn out to be a *Desmograptus*.

Representatives of this group were found in the Mississinewa shale in the quarry one-half mile east of Yorktown, Indiana; in the quarry one-half mile south of Markle; and in the railroad cut at Wabash Station, Wabash, Indiana.

Specimens of *Desmograptus micronematodes* (Spencer) have also been reported from the Niagaran dolomites at Hamilton, Ontario, and from the Gasport member of the Lockport limestone at Lockport, New York.

Desmograptus micronematodes magnus, n. var.

Fig. 13b.

Description.—The rhabdosome of this variety is flabellate, the width decreasing, on one of our specimens, from 56 mm. at the distal extremity to 25 mm. within a distance of 45 mm., giving an angle of divergence of the sides of the frond approaching 20°. The proximal portion of the frond is missing. The branches average from 0.35 to 0.4 mm. in width, have corneous texture, and are longitudinally striated. They coalesce at regular intervals with their neighboring branches or are joined with them by short, thick dissepiments which are usually oblique. The meshes thus formed are elliptical, oblong or biconvex, varying from 0.8 to 1.3 mm. in length and from

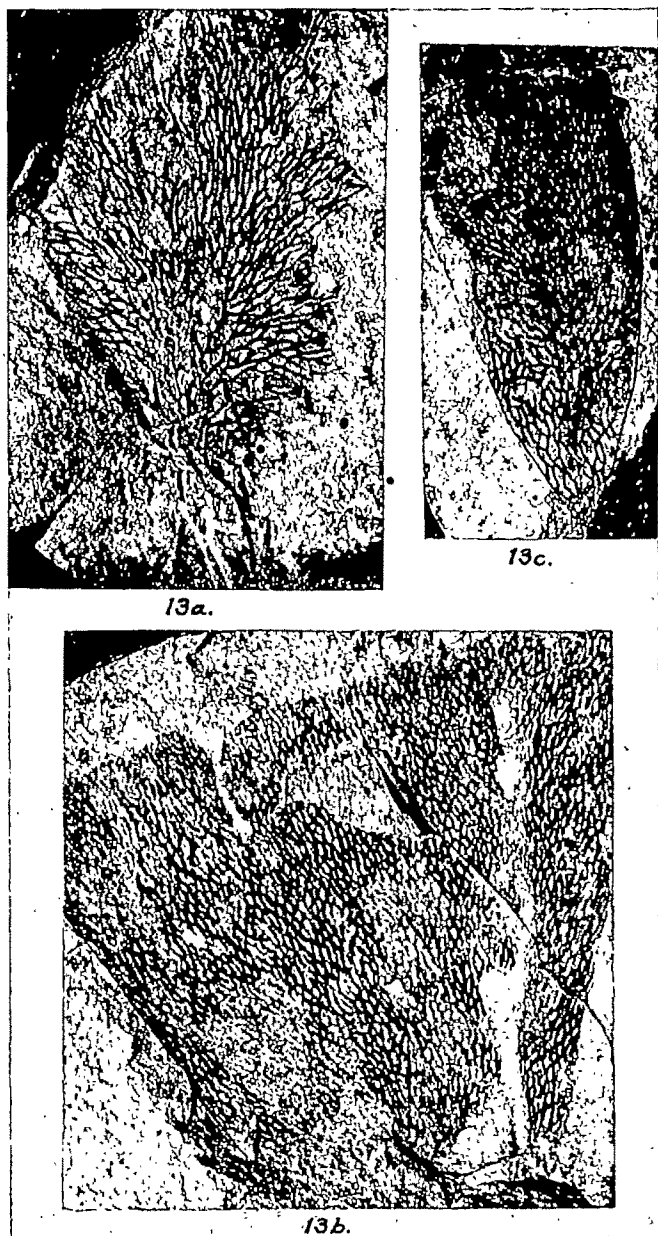


Fig. 13.

0.4 to 0.5 mm. in width. The form of the frond is very characteristic. The structure made by the coalescing of the branches is rather regular. Although poorly defined, there seem to be about four thecae in 1 mm. They are usually not visible.

This variety is closest to the specimens included under Group No. 1 of *D. micronematodes* described above. It varies from them, however, in shape and size of frond and in the regularity of the structure.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana, and in quarry one-half mile south of Markle, Indiana.

Thallograptus cervicornis (Spencer).

Figs. 9f, 11a, 11g.

Inocaulis cervicornis Spencer, Canadian Nat., 10, 1882, p. 165 (nom. nud.); Trans. Acad. Sci. St. Louis, 4, 1884, p. 587, pl. 5, fig. 5; Bull. Mus. Univ. State Missouri, 1, 1884, p. 37, pl. 5, fig. 5.—Gurley, Jour. Geol., 4, 1896, pp. 99, 308.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, p. 51, fig. 65; Bull. U. S. Nat. Mus., 92, 1915, p. 665.

Thallograptus cervicornis Ruedemann, Bull. N. Y. State Mus., 265, 1925, pp. 35, 36.

Description.—The Mississinewa shale at Yorktown has yielded one nearly complete specimen and numerous fragments of this species. It seems to be rather common in the shale. These specimens agree in general structure with Spencer's type (see Bassler, 1909), but exhibit considerable variation in size. Figs. 11a and 11g show several stipes of a normal specimen, while Fig. 9f shows a much smaller specimen.

This smaller rhabdosome is 2.5 cm. wide and 1 cm. high, with an average width for the stipes of 0.8 mm. Just before bifurcation the stipe may swell to a width of 1.2 mm. The stipes are 1 cm. or less in length and have from 4 to 5 branchlets which rarely exceed 2 mm. in length and 0.1 mm in

Fig. 13.

- 13a. *Desmograptus cumingsi*, new species. The type-specimen, $\times 1.5$.
- 13b. *Desmograptus micronematodes magnus*, new variety. Type-specimen, $\times 1.5$, from Yorktown, Indiana.
- 13c. *Desmograptus micronematodes* (Spencer). From Yorktown, Indiana. A poorly-preserved frond, $\times 1.5$, representing Group No. 1.

width. Our specimen has five well-developed stipes which appear to have been connected by some sort of runner. When compared with the type this specimen is seen to be only half as large. Several incomplete specimens indicate that they are parts of even smaller rhabdosomes. It does not seem advisable, however, to make a new variety of these smaller forms at present.

The texture of the stipes is corneous. The surface of the branches is striated in some of the specimens. In the smaller specimen described above, an apparently solid rod is present on one of the branches. This rod is 0.2 mm. in width and where the original carbonaceous material is exfoliated a slender groove indicates where it has been.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana, and in quarry one-half mile south of Markle, Indiana. This species is also found in the Niagaran dolomites at Hamilton, Ontario.

Thallograptus phycoides (Spencer).

Fig. 11f.

Inocaulis phycoides Spencer, Canadian Nat., 10, 1882, p. 165 (nom. nud.); Trans. Acad. Sci. St. Louis, 4, 1884, pp. 565, 588, pl. 5, figs. 6, 7; Bull. Mus. Univ. State Missouri, 1, 1884, pp. 15, 38, pl. 5, figs. 6, 7.—Gurley, Jour. Geol., 4, 1896, pp. 99, 309.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 51, 52, fig. 66; Bull. U. S. Nat. Mus., 92, 1915, p. 666.

Thallograptus phycoides Ruedemann, Bull. N. Y. State Mus., 265, 1925, pp. 36, 37, text fig. 23.

Description.—One incomplete frond of this species, measuring 22 mm. across and 18 mm. high, was found at Yorktown. The frond consists of three main branches, about 1 mm. in width and from 2.5 to 4 cm. in length, which seem to arise from a common branch. Smaller branches are given off at frequent intervals along the main branches. Except for the slender character of the branches, the specimen agrees fairly well with the type as figured by Bassler (1909, p. 51, fig. 66). Our specimen probably represents the distal portion of a large frond.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species has also been reported from the Niagaran formations at Hamilton, Ontario, and from the Rochester shale at Lockport, New York.

Inocaulis ramulosus Spencer.

Figs. 3, 4.

Inocaulis ramulosus Spencer, Trans. Acad. Sci. St. Louis, 4, 1884, pp. 565, 588, 589, pl. 6, fig. 1; Bull. Mus. Univ. State Missouri, 1, 1884, pp. 15, 38, 39, pl. 6, fig. 1.—Gurley, Jour. Geol., 4, 1896, pp. 99, 309.

Inocaulis ramulosus Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 49, 50, figs. 63, 64; Bull. U. S. Nat. Mus., 92, 1915, p. 667.—Ruedemann, Bull. N. Y. State Mus., 265, 1925, p. 28, text fig. 19.

Description.—Two small fragments representing incomplete specimens of *Inocaulis ramulosus* were found in the Mississinewa shale. One was found in the shale on the flank of the



Fig. 3. *Inocaulis ramulosus* Spencer. Camera drawing of incomplete rhabdosome from Markle, Indiana (natural size). This specimen also resembles *Thallograptus phycoides* very closely.

large reef near the Big Four railroad station in Wabash, Indiana, and the other in the shale lens from the quarry one-half mile south of Markle, Ind.



Fig. 4. *Inocaulis ramulosus* Spencer. Camera drawing of an incomplete specimen (natural size) from Wabash, Indiana.

The branches vary from less than 1 mm. to over 2 mm. in width, are covered with rope-like longitudinal striations, and have corneous texture. Dichotomy sometimes gives rise

to a prong-like extremity at the end of the branches. This feature, along with the projecting thecae, indicates that the specimens are to be referred to *Inocaulis*. The thecae, which are always poorly preserved, appear to have projected above the surface of the branches, for they now appear as rings of corneous material or as circular depressions where the original material has been exfoliated. They are regularly 1 mm. apart. Rudimentary branchlets are sometimes given off from the main branches. Fig. 3 shows the specimen found at Markle. It is very close to Ruedemann's (1925, p. 28) Fig. 19.

The specimen from Wabash (Fig. 4), is nearest *ramulosus*, but does not seem to fit exactly the description given by Bassler (1909, pp. 49-50). It does, however, closely approximate the distal portion of that species as figured by Ruedemann (1925, Fig. 19).

Horizon and locality.—Mississinewa shale near the Big Four station at Wabash, Indiana, and in the quarry one-half mile south of Markle, Indiana. This species is also found in the Niagaran dolomites at Hamilton, Ontario, and in the Gasport member of the Lockport limestone at Gasport, New York.

Acanthograptus walkeri (Spencer)

Fig. 5.

Inocaulis walkeri Spencer, Canadian Nat., 10, 1882, p. 165 (nom. nud.); Trans. Acad. Sci. St. Louis, 4, 1884, p. 585, pl. 5, fig. 2; Bull. Mus. Univ. State Missouri, 1, 1884, p. 35, pl. 5, fig. 2.—Gurley, Jour. Geol., 4, 1896, pp. 99, 309.

Acanthograptus walkeri Ruedemann, Mem. N. Y. State Mus., 11, 1908, p. 194, figs. 97, 98, pl. 6, figs. 1, 2; pl. 7, fig. 4.—Bassler, Bull. U. S. Nat. Mus., 65, 1909, pp. 57-59, figs. 75-80; Bull. U. S. Nat. Mus., 92, 1915, pp. 2, 3.—Ruedemann, Bull. N. Y. State Mus., 265, 1925, pp. 19, 20, figs. 3, 4.

Acanthograptus bartonensis Grant, Jour. and Proc. Hamilton Assoc., 16, 1900, p. 101 (fig. only).



Fig. 5. *Acanthograptus walkeri* (Spencer). Camera drawing of two fragmental branches which overlap (natural size). Thecae are shown by small round dots.

Description.—Several fragments found at Yorktown agree rather closely with this species. The branches average slightly less than 1 mm. in width, and are sometimes covered by several rows of rod-like or rope-like ridges which give the branch a striated appearance. The texture is corneous. On one of the branches several rod-like processes project outward from the surface of the branch at a low angle. These rods do not appear to be over 0.1 mm. in thickness, and do not exceed 1 mm. in length. On another branch, the surface of which has been exfoliated, were four thecae within the distance of 1 mm. They were represented by circular masses of carbonaceous material.

The most characteristic feature of the fragmental frond is the great number of short, spine-like projections which occur along the sides of the main branches. Some of these branches or spines are pointed while others are blunt. Some are very short, being scarcely recognizable, while others may reach 3 mm. in length. In the figure there are probably two fragments which overlies each other, but the preservation was too poor to be sure where the overlapping was.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. This species has also been reported from the Niagaran formations at Hamilton, Ontario; from the Gasport member of the Lockport limestone at Gasport, New York; and from the Rochester shale at Middleport, New York.

Medusaeograptus (?) mirabilis Ruedemann.

Medusaeograptus mirabilis Ruedemann, Bull. N. Y. State Mus., 265, 1925, pp. 8, 32-33, pl. 9, figs. 1-6; pl. 10, figs. 1-4; pl. 11, fig. 1.

Description.—Numerous fragments, which may represent the detached parts of a *Medusaeograptus*, were found in the Mississinewa shale east of Yorktown, Indiana. The fragments, usually in the form of long, slender strap-like stipes, vary from 0.5 to 1.5 mm. in width, and from 1 mm. to several centimeters in length. Some larger carbonaceous accumulations are also associated with the smaller fragments.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana. Ruedemann named the genus and species from specimens found in the Gasport member of the Lockport limestone at Gasport, New York.

Diplograptus, sp.

Description.—An incomplete stipe, found at Wabash, Indiana, seems very close to *Diplograptus*. The specimen is 17 mm. long, 0.7 to 0.8 mm. wide proximally and from 1 to 1.5 mm. wide distally. Thecae on either side about 1 mm. apart; 8 in 7 mm. near the proximal extremity opposite the nemacaulus (virgula). The nemacaulus is recognizable for almost the entire length of the stipe, being obliterated about 4 mm. from the proximal end. Where the original carbonaceous material is present the nemacaulus is seen as an apparently solid rod, but where the stipe is exfoliated, it is seen as a slender groove about 0.2 mm. wide. On our specimen the nemacaulus is located about 0.4 mm. from one side. Since both the distal and proximal extremities are missing, nothing can be said about either the extension of the virgula or the character of the spines. This species is new, for no other *Diplograptus* has, so far as the writer is aware, ever been reported from the Niagaran of the United States, but our specimen is too poorly preserved to serve as a type for a new species.

Horizon and locality.—Mississinewa shale on the flank of the reef near the Big Four railroad station at Wabash, Indiana.

Diplograptus (*Glyptograptus*) *niagarensis*, n. sp.

Figs. 6, 10f.

Description.—One incomplete rhabdosome belonging to this genus was found at Yorktown. This fragment is 14 mm. long. It widens rapidly from 0.2 to 1.7 mm. in a distance of a little over 10 mm. and retains that width distally. The sicular and antiscicular extremities are missing, hence nothing can be said concerning either the spines or the extension of the nemacaulus. Thecae are visible on both sides of the stipe, occurring about 1 mm. apart (14-15 in 14 mm.). They are inclined from 15° to 28° and overlap about one-third. The nemacaulus is not central on our specimen. It is marked by a slender groove (0.1 mm. wide) in the antiscicular half of the rhabdosome where the original material has been exfoliated, and by an apparently solid rod in the sicular half where the stipe is intact.

The finding of a *Diplograptus* in the Niagaran of this country is of no little interest. It indicates that this genus is not limited to beds below the Niagaran. Dr. Ruedemann and Dr. Bassler have been so kind as to check this generic determination (personal communication). Concerning the specimen Dr. Ruedemann wrote, "The *Diplograptus* is a form of the subgenus *Glyptograptus*, similar to some British Silurian forms, esp. *G. serratus*." The specimen from Wabash, referred to as *Diplograptus* sp., may very likely be a representative of this species.

Horizon and locality.—Mississinewa shale at quarry one-half mile east of Yorktown, Indiana.



Fig. 6. *Diplograptus* (*Glyptograptus*) *niagarensis*, n. sp.* Camera drawing ($\times 5$) of the type-specimen.

Monograptus falciformis, n. sp.

Figs. 7, 8, 10c.

Description.—On a slab of Mississinewa shale near "Double Cliffs" along the Mississinewa River, one and one-half miles above Red Bridge, were found four fragmental stipes closely resembling *Monograptus*.

The branches are falciform, being slightly more curved at the proximal extremity. Two stipes are nearly complete, except for the distal extremity, while the other two fragments

represent the distal portions of one or possibly two additional stipes. The texture is corneous and the surface of the stipes is somewhat scaly.

The two large stipes, approximately 1 and 2 cm. long, are very narrow at the beginning (there is some doubt about the sicula being preserved), being under 0.2 mm. in width, but rapidly (within 4-5 mm.) attaining their full width (1.3 to 1.5 mm.), which is maintained proximally (see Figs. 7 and 8).

The thecae are quite prominent on all the stipes; are broad (0.5 mm.) and relatively short (two and one-half to three times as long as wide); are inclined 35° to 40° ; overlap two-thirds or more of their length; and do not contract towards the aperture which is usually about normal to the



Fig. 7. *Monograptus falciformis*, n. sp. Camera drawing of an incomplete stipe (x 5).

axis of the thecae and straight. A slight contraction of the thecal tube towards the base and a slight expansion towards the aperture are characteristic of numerous thecae. Processes, which most likely represent spines, were noted on several thecae of one of the smaller fragments. The thecae as a whole are regular. They occur from 0.5 mm. to 0.7 mm. apart. (On one stipe, 13 in 8.5 mm.) At the base of a number of thecae on one of the larger stipes (Fig. 7) occur small conical-shaped masses of carbonaceous material. Where the original material of the stipe is exfoliated their presence is indicated by the occurrence of depressions. They are arranged in a line roughly paralleling the dorsal side.

This species is nearest *Cyrtograptus ulrichi* Ruedemann of any described American species, but differs from it markedly in several respects. The thecae are more highly inclined (35° — 40° as compared to 20°); are much more prominent and regular; occur on the inside (concave side) of the sickle-shaped stipe rather than on the convex side; and have thecae



Fig. 8. *Monograptus falciformis*, n. sp. Camera drawing of an almost complete stipe ($\times 5$).

more nearly like those of *Monograptus*. The rapid attainment of normal width is characteristic of the stipes, as is the smooth, regular-curving form. There is no indication on our specimens of any secondary branches, which are characteristic of *Cyrtograptus*, although our specimens are not complete. It is thought best, however, to refer the specimens to *Monograptus*.

Concerning these specimens Dr. Ruedemann has written (personal communication), "The *Monograptus* is very close to the European *M. bohemicus*, only narrower. It should

also be compared with my *Cyrtograptus ulrichi*, which is also very similar and may yet prove to be only a *Monograptus*, with larger collections." The discovery of an additional *Monograptid* in the Silurian (Niagaran) is of considerable interest, since it represents the occurrence in the Michigan Basin of a genus, heretofore known only from the Atlantic, Bohemian and Baltic basins.

Horizon and locality.—From the Mississinewa shale near "Double Cliffs" along the Mississinewa River, one and one-half miles above Red Bridge, Wabash County, Indiana.

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A MIOCENE PALIURUS FROM THE STATE OF WASHINGTON.

EDWARD W. BERRY.

A good illustration of the danger in restricting comparisons of fossil plants, even from horizons as late as the Miocene, to those of existing ecological groups of the same general region, is furnished by the recent discovery of the fruits of *Paliurus* in the late Miocene of the State of Washington. This interesting genus of the Rhamnaceae has but two or three existing species with a disconnected but by no means limited distribution in Eurasia, the ranges overlapping in southeastern temperate Asia. Paleobotanists have recorded a considerable number of fossil species, which will be referred to briefly in a subsequent paragraph. These fossil occurrences have been based almost entirely on impressions of leaves, and are dismissed by Potonié in the statement which he prepared for Engler and Prantl's *Natürlichen Pflanzenfamilien* with the comment that the foliage is not characteristic since other genera both in this and other plant families have similar leaves.

This is, of course, perfectly true, and leaves are to be identified with caution. There are some types, e.g. the narrowly lanceolate, that seem hopeless at present, but many others are entirely characteristic once the characteristic features have been determined. I am not sure that the leaves of *Paliurus* can be always certainly distinguished from those of some species of *Rhamnus*, *Zizyphus* or *Ceanothus*—to mention but three related genera that appear frequently in the geological record, but the fruits are entirely unlike those of any other Rhamnaceae, and as far as I am aware, equally unlike those of any other existing plants.

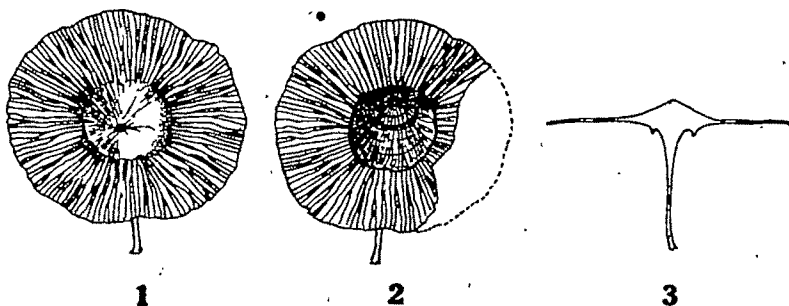
In *Paliurus* the slender peduncle expands distad into the conical base of the fruit surrounded by a ridge, collar or veil and then expands more rapidly upward, recurving to form a broad horizontal, veined wing, about as wide as the diameter of the fruit proper and continuous all around, so that it is nearly circular when viewed from above or below. Above the horizontal wing the central part is more or less domed with a central apical umbo or point. The substance is woody and contains usually three cavities, in two of which were matured seeds in the specimen dissected, the third seed being abortive and the cavity small.

The material upon which this note is based was collected by T. A. Bonser at Grand Coulee, Douglas County, Washington, from diatomaceous clays which apparently represent approximately the same horizon as the Latah formation of the Spokane area.

The species, which is new, may be described as follows:

Paliurus hesperius Berry, n. sp. (Figs. 1-3).

Fruit discoidal, peltate, pedunculate; the essential part depressed turbinate, the margin extended horizontally as a broad scarious, veined wing. The wing margin is irregularly sinuate. The veins are radial in direction, slightly undulate and may be simple or once or twice forked.



Figs. 1-3. *Paliurus hesperius* Berry, n. sp. from Grand Coulee, Washington. $\times 2$.

As preserved the whole fruit departs slightly from circular in outline, being 1.2 by 1.6 centimeters in diameter. The enlarged central essential part is 6 millimeters in diameter. The type comprises two specimens which are counterparts, split in the plane of the wing, which is well preserved. The fruit substance is gone in the central part of both specimens and was probably lost when the specimen was split open, since one counterpart shows the cast of the apical umbone above the wing, and the other shows a cast of the proximal part below the wing. These are slightly deformed by pressure during fossilization but preserve the details in a remarkable way and have served for the reconstructed median longitudinal section shown in the accompanying Fig. 3. Fig. 1 shows the fruit viewed from below pressed down over the peduncle which is seen projecting below the wing margin. In the center is the

cast of the rounded apex, with a prominent conical tip from which impressions of the veins radiate. The impression is darkened around the margin of the umbo where the substance is preserved at the inner margin of the wing.

The counterpart shown in Fig. 2 is similar except in the center where there is preserved the deep cast of the conical part of the fruit below the wing, somewhat offset. This shows clearly the collar around the upper expanded end of the peduncle and the scar where its distal end was attached to the base of the fruit. The material is almost as good as a recent *Paliurus* fruit, and is much better for having the resistant substance of the fruit proper gone, since both surfaces can be studied, one of which would have inevitably been concealed had it not dropped out when the clay was split.

The fossil agrees with the fruits of the recent species of *Paliurus* in every feature except that it is slightly smaller, in this respect being closest to the existing *Paliurus aculeatus* Lam., although the existing forms show considerable variation in the size of their fruits and I have not enough material to be sure of the limits of variation in either the existing or fossil forms. The fruits of *Paliurus aculeatus* which I have seen are more robust, with a larger essential part which is much more massive proximad below the wing, with the wings thicker, the venation less visible, and the peduncle shorter. The fossil is more like the fruits of *Paliurus orientalis* Franchet which I have seen in relative proportions, in the thinner wing with greater visibility of the veins, and in the relative length of the peduncle. No leaves are directly associated with the fossil but at approximately the same horizon both at this locality and in the Latah formation at Spokane there are leaves of a *Paliurus* which are nearer to *Paliurus orientalis* than they are to the other existing species. It is probable that leaves and fruit represent the same Miocene species but this cannot be demonstrated at present. Although the probability is great, reasonable caution demands that the fruit and foliage be separately named until such time as their relationship to one another can be more certainly shown.

The genus *Paliurus* of Jussieu contains two or three existing species of shrubs or small trees with cordate or ovate, palmately 3-veined and usually small leaves with stipular thorns. The fruits, as already mentioned, are coriaceous, peltate, umbonate, with a horizontal marginal radiately veined wing. In existing floras *Paliurus* is restricted to dry soil habitats from Spain

on the west to Japan on the east. *Paliurus aculeatus* Lamarck extends from Spain through southern Europe, Asia Minor, Crimea, the Caucasus and Persia to China (Szechuan). *Paliurus ramosissimus* Poiret extends from about 27° north latitude in Kiang Si to Japan, and *Paliurus orientalis* Franchet, sometimes united with the preceding, reaches the stature of a thin tree sometimes 50 feet tall in eastern Szechuan and Shenzi, China.

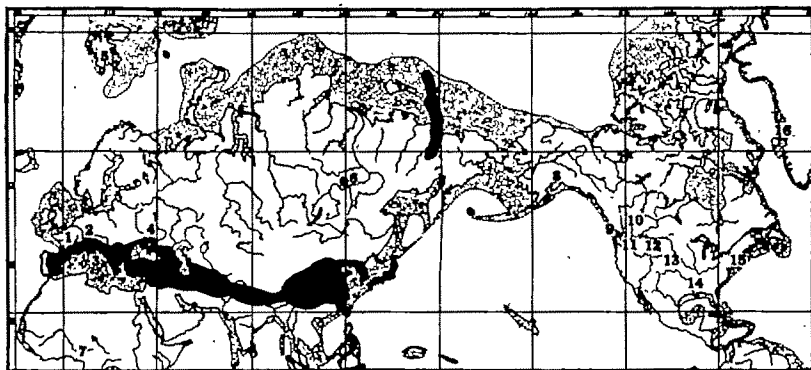


Fig. 4. Sketch map showing existing range and geological occurrences of *Paliurus*. 1. Oligocene, Miocene and Pliocene of France. 2. Miocene of Alsace, Switzerland, Baden, Silesia, Styria and Bohemia. 3. Miocene of Italy. 4. Late Miocene of south Russia. 5. Eocene (?) of Spitzbergen. 6. Eocene (?) of Siberia. 7. Eocene (?) of Nigeria. 8. Kenai formation of Alaska (late Eocene). 9. Upper Cretaceous of Vancouver Island. 10. Upper Cretaceous and Eocene of Western Canada. 11. The new species from the Miocene of Washington. 12. Early Eocene of Montana and Wyoming. 13. Dakota sandstone of Kansas, Laramie and Miocene of Colorado. 14. Eutaw formation of western Georgia, lower Eocene of western Tennessee and Oligocene of Louisiana. 15. Upper Cretaceous of New Jersey, Staten Island and Long Island. 16. 1 Patoot (Upper Cretaceous) and 3 late Eocene of western Greenland.

Whatever the taxonomic distinction of the three, their ranges overlap, and the geological record is sufficiently complete to show that their present range is a restricted one, and that they represent relict species.

Turning now to the geological record, it may be noted that a considerable number of fossil species have been described, based for the most part on leaves and therefore subject to the uncertainties to which I have already alluded attending the identification of this class of remains.

The oldest records embrace about a dozen species, so called,

of leaves, from the Upper Cretaceous. These include 4 from the Dakota sandstone of Kansas, one from the Patoot beds of Greenland, 2 from the Mill Creek beds of western Canada, one from Vancouver Island, one from the Eutaw formation of Georgia, 3 from the Magothy formation of New Jersey, Staten and Long Islands, and one from the "Laramie" of Yellowstone Park. Many of these are very similar to the leaves of the existing species, but lack the corroboration of associated fruits or structural remains.

The Eocene has furnished at least 10 nominal species including occurrences in western Greenland, Spitzbergen, Siberia and Alaska on the north, and in British Columbia, Montana, Colorado and Wyoming in the western part of North America. I have described 3 species from the Wilcox group (lower Eocene) of the Mississippi embayment, and one of these is represented by characteristic fruits (1).¹ Seward (2) has described a large fruit from the supposed Eocene of southeastern Nigeria which has the appearance of a *Paliurus* but which is not certainly such.

The Oligocene contains at least 3 species—one from Louisiana represented by very characteristic leaves and thorny stems, and 2 from southeastern France represented by both leaves and fruit.

There are at least 13 nominal species recorded from the Miocene. These include identifications based upon leaves in Alsace, Switzerland, Bohemia, Italy, France, Silesia, and 2 from Florissant, Colorado, the last not conclusive in themselves, but highly probable in view of the occurrence of typical fruits at the same Miocene horizon in the state of Washington. Miocene species based upon fruits include occurrences in Bohemia and Styria, (3) Switzerland (4) and southern Russia scarcely if at all distinguishable from the existing *Paliurus* (5). The last, which comes from the Sarmatian stage, is *aculeatus*. The Pliocene record consists of a typical fruit (6) from central France (Cantal) which is also indistinguishable from the existing *Paliurus aculeatus*.

In view of what we know of the plant history of the Tertiary it is surely of interest that this new Miocene species from Washington should be most similar to the restricted species of south central China (*P. orientalis*) as are also the leaves associated with the fruit, and that there should be earlier (late

¹ Numbers in parentheses indicate references at the end of this article.

Eocene) species in the intervening region in Alaska and Siberia.

I have recently (7) discussed the resemblances and differences between the Miocene floras of the western United States and those two existing floral preserves in southeastern Asia and southeastern North America, so that this need not be restated in the present connection, but the present species of *Paliurus* is an interesting addition to the list of genera, no longer represented in North America which has nearly related species in southeastern Asia.

The accompanying sketch map (Fig. 4) shows the approximate range of the 3 existing species of *Paliurus* in solid black and the general location of the fossil records (both verified and unverified identifications).

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- (1) Berry, Edward W., U. S. Geol. Survey Prof. Paper 91, p. 279, pl. 71, fig. 4, tf. 14, 1916.
- (2) Seward, A. C., Geol. Survey Nigeria Bull. 6, p. 75, pl. 1, Fig. 5, 1924.
- (3) Ettingshausen, C. von., Foss. Fl von Bilin, pt. 3, p. 39, pl. 50, figs. 6, 7, 1869.
- (4) Heer, O., Fl. Tert. Helv., Bd. 3, p. 76, pl. 122, figs. 27-29, 1859.
- (5) Kryzhtofovich, A., Bull. Imp. Acad. Sci., St. Petersburg, 1914, No. 9, p. 592, pl. 1, fig. 1.
- (6) Langeron, M., Bull. Soc. d'hist. nat. d'Autun, 15, p. 85, pl. 6, tf. 1, 1902.
- (7) Berry, Edward W., Scientific Monthly, 25, pp. 321-328, 1927.

PHYSIOGRAPHIC INVESTIGATIONS IN QUEENSLAND WITH REFERENCE TO THE GREAT BARRIER REEF.

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As far as the geologist is concerned a sea-level coral reef is silent as to its origin. Only by studying the physiographic history of land masses associated with the reefs can any information be gained as to their origin and probable thickness.

To W. M. Davis we owe these fundamental concepts. For nearly twenty years this scientist has devoted much attention to the coral reef problem and his field studies and critical analyses of the available data have brought about a complete change in the methods of attack on the problem. He has pointed out the peculiar conditions which obtain along what he calls the Marginal Belts of the Coral Seas; he has appreciated the significance of cliffed islands in the Coral Seas; he has pointed out the importance of examining the nature of the reef-contact with the basement rocks in the case of elevated reefs; and he has described the origin and significance of plunging cliffs, thus affording a further test of the Glacial-control Theory.

The student of the coral reef problem may now go into the field armed with a vast quantity of detailed knowledge gathered from Davis' numerous papers—studies which are the result both of field work and of keen analytical reasoning in the laboratory. In commencing his work he already perceives the physiographic consequences of the various conflicting theories, and has a knowledge of the physiographic features of coast-lines and islands which provide critical tests of their validity.

The fact that in many cases barrier reefs and atolls stand on the marginal areas of submarine banks or platforms has been realized to be of great importance, and gradually geological interest has been transferred from the living structures of the reefs themselves to the basement platforms on which they rest. Physiographic investigations which bear upon the origin of these platforms—in some cases continental shelves—are of

* This research was carried out by the writer as a Science Research Scholar of the University of Sydney.

paramount importance. Recognizing this, the Great Barrier Reef Committee (formed in 1923 of representatives of Australian scientific bodies) has from the outset actively encouraged this aspect of research. The work of the Committee has recently been summarized in this Journal by the late Chas. Hedley.¹

Along the Queensland coast between the latitudes of Bowen (20°S.) and Gladstone (24°S.), a distance of about 250 miles, the area between the Barrier Reef complex and the mainland coast is littered with festoons of high, rocky islands. With the exception of Jardine's² account of the islands off Keppel Bay, near Rockhampton, the festoon islands, which attain a better development further north, have not been studied in detail.

During 1925 the writer made a physiographic study of the Bowen District and the northern islands of the Cumberland Group, (Whitsunday Passage).³ The physiography and geology of this area is of particular interest, for this is the region selected by Davis,⁴ after a personal examination of the Queensland coast, as showing particularly well the evidence of submergence and other incidents in the admittedly complex history of the coast and the Great Barrier Reef.

During 1926 the same line of investigation was continued by an examination of the high rocky islands and the mainland coast from Gladstone northwards to the Whitsunday Passage. By permission of the Australian Naval Board and by courtesy of Capt. J. A. Edgell, O. B. E., R. N., the writer was accommodated in H. M. A. S. *Moresby*, thus gaining unique opportunities for research. I wish, therefore, to acknowledge the courtesy and valuable assistance which I received from everyone on board, and especially from my own messmates, the Wardroom officers.

The reefs and the high rocky islands are to be considered as but two of the units in a broad province as follows (passing from east to west,—from unstable to more stable conditions):—

- (a) True atolls of the Coral Sea, such as Willis, Lihou and Saumarez Reefs;

¹ Hedley, C., this Journal, 11, 187-193, 1926.

² Jardine, F., Rep. Gt. Barrier Reef Commission, 1, 83-86, 1925 (Trans. Roy. Geograph. Soc. Asia).

³ Stanley, G. A. V., Rep. Gt. Barrier Reef Commission, 2, 1-51, 1927.

⁴ Davis, W. M., this Journal, 44, pp. 339-350, 1917.

- (b) The complex zone of coral reef units known collectively as the Great Barrier Reef;
- (c) Festoons of high rocky islands, formed of rocks similar to those of the mainland, usually deeply embayed, and with numerous fringing reefs;
- (d) The coastal plains and coastal ranges of the mainland;
- (e) The highlands of Eastern Australia, which are broad "plateau" masses, deeply dissected around their margin, and traversed by valleys parallel to the coastline, such as the Dawson-Mackenzie system and the upper Burdekin.

The present investigation deals partly with the second but mainly with the third of these sub-provinces.

The Great Barrier Reef is some 1,200 miles long, and stretches between Bramble Cay in Torres Straits and Lady Elliot Island near Breaksea Spit. It may be divided into several sections which present rather distinct characteristics. The reefs form a zone which towards the north become progressively narrower and gradually approaches the coastline up to a point near Cape Melville, north of which the outer edge gradually recedes again. (See Table I.) Where closest to the coastline the zone is narrowest.

At the south end the Bunker and Capricorn Groups are tabular, atoll-like masses standing on a platform which slopes gently to the eastward to a depth of about 40 fathoms, at which point there is a steepening of the submarine profile. These reefs lack, however, a central lagoon. Vegetated islets, clearly derived from reef detritus, are common on the leeward (north-west) side. The inter-reef depths are 20-30 fathoms.

These reefs are separated by the deep reef-free Capricorn Channel from Swain's Reefs, which present different features. Here the reef zone is broadest and farthest from the coastline. The reefs are of the horseshoe type with central lagoons. They stand clustered on a sloping shelf with depths of 30-40 fathoms between them. Vegetated islets are practically unknown and sand cays are rare. This condition persists as far north as Cooktown where a group of reefs of this type has been well described by Hedley and Taylor.⁵ North of this the reef zone is narrower, the outer units are linear and more truly barrier-like, while at the same time the inner edge approaches closer to the coastline. To the north again the reefs of Torres Straits resemble the Capricorn type, though the inter-reef depths are much less.

⁵Hedley, C. and Taylor, T. G., Aust. Assoc. Adv. Sci., 1907.

TABLE I.

Lat.		Mainland Coast to Inner Edge of Reef Zone	Mainland Coast to Outer Edge of Reef Zone	Width of Reef Zone
11°	Cape York	6 (ill defined)	65	59
12°	Cape Grenville	6	35	29
13°	Cape Direction	7	19	12
14°	Cape Melville	6	15	8
15°	Cape Flattery	8	20	12
16°	Cape Tribulation	10	25	15
17°	Cairns	15	30	15
18°	Cardwell	20	35	15
19°	Townsville	35	60	25
20°	Bowen	35	75	40
21°	Mackay	40	100	60
22°	Swain's	75	120	45
24° } 23° }	Capricorn	{ 30 25	50 35	20 10

Behind the reefs, and separated from them by a "lagoon" or reef-free zone, are the festoon islands of continental rock. They project up through the sediments of the broad, gently-sloping shelf, on the ocean side of which the Reef Zone is situated. They conform with few exceptions to type. All are well dissected and embayed. Cliffling is of relatively small extent, being confined to plunging cliffs in the more easterly members of the groups modified by small cliffs which are being eroded at the present day. Reefs are confined to those of the fringing type. They are developed chiefly in the bays, and are either very narrow or entirely absent on the headlands. There is not a single example of a barrier-reef-encircled island, such as would be expected in accordance with the theory of long continued, intermittent subsidence. In the case of island groups such as those around the Whitsunday Passage there is abundant evidence of drowning, yet no barrier reefs have been developed, nor do the charts reveal evidence of drowned barrier reefs. Forty miles to the eastward are the horseshoe reef units of the Great Barrier clustered on a broad, gently sloping shelf. It does not seem that these can have been developed on entirely Darwinian lines.

The following is a preliminary statement as to the origin of the Great Barrier Reef. The discussion will be presented in detail in the Reports of the Great Barrier Reef Committee.

- I. The present coastline of Queensland was initiated by subsidence and fracturing of the continental margin

in pre-Glacial times. The degree of dissection of the mainland ranges and the larger islands, when contrasted with the relatively small extent of marine abrasion, indicates that the pre-submergence period of sub-aerial erosion was of relatively long duration.

- II. During the Glacial period there was a lowering of sea-level (to an extent which cannot very easily be determined, but which may be of the order suggested by Daly) in accord with the Glacial-control Theory.
- III. Abrasion by the lowered ocean produced plunging cliffs, which are developed around certain of the islands, such as the eastern members of the Cumberland and Northumberland Groups, and some of the Keppel Isles.
- IV. Inasmuch as the fluctuations of sea-level during the Glacial period affected the reefs, the Glacial-control Theory is supported. Although a lowering of sea-level during the Glacial period is accepted, no positive support can be given to the view that the Great Barrier Reef Zone is built on a rock shelf abraded around the continental margin by the lowered ocean. The fluctuations of sea-level are regarded merely as complicating incidents in the evolution of the reefs and the continental shelf, but they have not exercised a major control.
- V. The Great Barrier Reef as we see it at the present day has attained its development chiefly during post-Glacial time.
- VI. During the Glacial period reefs may have existed as far south as Cairns (lat. 17° S.). South of this they would be inhibited by climatic conditions. Thus to the north of Cairns the present reefs may have had continuous growth and are to be regarded as the successors of a long series of reefs dating from the pre-Glacial submergence of the continental margin, the growth conditions having been modified from time to time by changes in temperature and sea-level. To the south of Cairns the present development is entirely post-Glacial.
- VII. It is on the continental shelf of Eastern Australia that the units of the Great Barrier Reef Zone have settled and are building. The problem thus shifts to a consideration of the origin of the continental shelf.
- VIII. The views of Andrews, Hedley and Taylor, Vaughan, and Agassiz (to some extent) are supported.
- IX. The Darwinian theory of reef upgrowth during long-continued and intermittent subsidence is held to be

invalid in explaining the present Reefs even though it has received the powerful support of Davis after a personal study in the field.

- X. The down-flexing and faulting of the continental margin produced the undermass of the continental shelf, and where drowning was only partial, produced a coastline of dominant subsidence. On the submerged areas corals took the opportunity of building reefs.
- XI. During post-Glacial time there has been considerable aggradation of the continental shelf; and the continental shelf of Glacial times is covered by a considerable thickness of Recent material.
- XII. It appears possible that along the northern portion of the Queensland coast the continental shelf may be composed partly of the remains of pre-Glacial reefs (see VI).
- XIII. Borings through reef units (such as that carried out during 1926 at Michaelmas Cay near Cairns, by the Great Barrier Reef Committee) should be interpreted in view of the physiographic evolution and probably constitution of the particular area of the continental shelf on which the unit is situated. A bore made at a point a good deal north of Cairns would probably reveal a very different section to one made at the south end of the Reef Zone. The presence of coralline material at a considerable depth (say 1,000 feet) in the former case would not conclusively support the Subsidence Theory, as explaining the origin of the entire present day Great Barrier Reef Zone.

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EXPERIMENTS IN UNDERTHRUSTING.

GERALD R. MAC CARTHY.

INTRODUCTION.

The experiments herein described had a twofold object i.e., to determine, if possible, the conditions under which underthrust faults and overturned folds might be formed, and to study the effects produced by a plastic supporting layer on the form of the structures developed by compression in the materials above it. By overturned folds and overthrust faults are meant folds and faults in which the upper portion possesses the active motion during formation, and likewise by underturned folds and underthrust faults are meant folds and faults in which the lower portion actually moved during formation of the structure.

The reality of isostasy is assumed, although no special mechanism of isostatic adjustment is invoked. Whether one holds with the Airy or "roots of mountains" theory, with the Hayford conception of compensation at a definite depth, or with Chamberlin's idea of "elastasy,"¹ the basic idea involved is that at some depth within or below the outer crust there exists sufficient plasticity or pseudoplasticity to permit of vertical movements of considerable magnitude. It is further assumed that relief features of the magnitude of mountain ranges are more or less completely compensated. This freedom to move vertically in response to changing loads is all the isostasy here assumed, although for purposes of discussion a more or less definite level of compensation is postulated.

Previous pressure box experiments. Previous experiments such as those of Willis² and of Chamberlin and Shepard³ would seem to indicate that underthrusts and underfolds are of very minor importance. It seems to be very generally considered that all major thrusts and folds are of the nature of overthrusts although several workers, notably Hobbs⁴ and Law-

¹ Chamberlin, T. C., Certain phases of megatectonic geology, *Jour. of Geol.*, 34, 1, 1926, and Elastasy vs. isostasy, *Jour. of Geol.* 35, 89, 1927.

² Willis, Bailey, 13th Ann. Rep. U. S. Geol. Survey, pt. II, 217, 1889.

³ Chamberlin, R. T., and Shepard, F. P., Some experiments in folding, *Jour. of Geol.*, 31, 490, 1923.

⁴ Hobbs, W. H., Earth evolution and its facial expression, p. 119, and Mechanics of formation of arcuate mountains, *Jour. of Geol.*, 22, 71 and 166, 1914.

son,⁵ are strong advocates of the importance of this type of structure, Lawson's discussions being based chiefly upon theoretical considerations and Hobbs' upon personal interpretation of field evidence and certain experiments. It seems to the writer that in previous experiments underthrusts have not been given a fair chance to develop, a major factor in their production having been lacking. This major factor is the plasticity or pseudoplasticity which must be present at great depths if the theory of isostasy corresponds in any degree to actual crustal conditions.

In describing his well-known series of experiments Willis⁶ remarks that

"After a number of experiments I began to be embarrassed to explain the constant occurrence of an anticline at the end of the model nearest the piston."

This phenomenon was of course due to the fact that the wax layers forming the model were incompetent to transmit thrusts to any great distance unless all tendency to bend was rigidly suppressed and, since the rigid bottom of the pressure box used by him prevented all downward movement, the materials under compression bulged upward to form anticlines which seem to have been more of the character of over- than of under-turned folds. If crustal plasticity does increase with depth the rocks of the outer zone alone would be capable of transmitting lateral thrusts over any appreciable interval of time, and instead of the rigid and unyielding bottoms of Willis' and of Chamberlin's pressure boxes a yielding and sensitively self-adjusting support is called for if conditions in the pressure box are to reproduce as accurately as possible the conditions under which such structures as the Appalachian folds were formed. It is perhaps worthy of note that in his original paper Willis states that one of the conditions necessary to reproduce as accurately as possible natural conditions is a plastic substratum and on the same page says "the support of the superficial crust is latently plastic."⁷ He therefore supplied his wax models with a plastic foundation but subjected this foundation to the same deformative processes as the

⁵ Lawson, A. C., Isostatic compensation considered as a cause of thrusting, *Bull. Geol. Soc. Am.*, 33, 337, 1922, and Folded mountains and isostasy, *Bull. Geol. Soc. Am.*, 38, 263, 1927.

⁶ Willis, Bailey, 13th Ann. Rep. U. S. Geol. Survey, pt. II, 241, 1889.

⁷ *Op. cit.*, p. 241.

models themselves, invariably creating an up-bulging in front of the advancing piston. In nature there is no rigid foundation beneath the plastic zone and the more or less horizontally compressed materials in the zone of flow at the base of the deformed mass are almost as free to move downward or sideways as they are to bulge upward: hence no anticline need form at once. To do away with this artificial condition as nearly as possible it was determined to avoid all compression of the plastic support since, although there doubtless is lateral compression in the corresponding crustal zone, relief from such compression may be obtained by movement of the plastic material in any direction. In fact, if we are to believe many isostasists, the downward motion at the bottom of a thick mass of slowly crumpling sediments should, barring contemporaneous erosion, far exceed the upward motion at the top of the same mass.

THE APPARATUS USED.

In planning this series of experiments it was at first proposed to float the wax models upon a bath of mercury or other heavy liquid, thus assuring perfect adjustment to all vertical stresses. Preliminary experiments soon showed that this scheme was not feasible, and various substitutes for the mercury were tried. An inflated rubber bag made from an old inner tube proved somewhat better, but was still very unsatisfactory, the expansion of the enclosed air introducing too many complications. Eventually a basal layer of plastic modeling clay (rendered more plastic by the addition of large quantities of vaseline) was adopted as being at the same time both easily manipulated and as reproducing with reasonable accuracy the conditions of plasticity demanded by the theory of isostasy. The pressure box used was modeled upon that described by Willis^{*} but was smaller, the internal dimensions being but six by twenty inches. Pressure was applied through a plunger or piston composed of a solid block of oak actuated by an automobile jack of one ton capacity. This plunger entered the box three inches above its floor, a series of wooden strips cut to fit the bottom of the box being provided so that by the insertion of one or more of them the effective rigid bottom of the box could be raised to any desired elevation short of the lower surface of the piston. Fig. 1 shows a side view of the box

^{*} Op. cit., Description: p. 242, plate facing p. 258.

with the removable wall taken off and several of these floor strips in place. The overburden used was lead shot of "T" size, vertical pressures up to four pounds per square inch being thus available. The materials experimented upon were, in the majority of cases, wax layers of varying degrees of competency, different mixtures of paraffine and vaseline (in a few cases cylinder oil) being used in accordance with Chamberlin's suggestions.⁹ Where brittleness was desired thin layers of plaster or of plaster and sand were employed, while extremely incompetent strata were represented by strips of modeling clay.

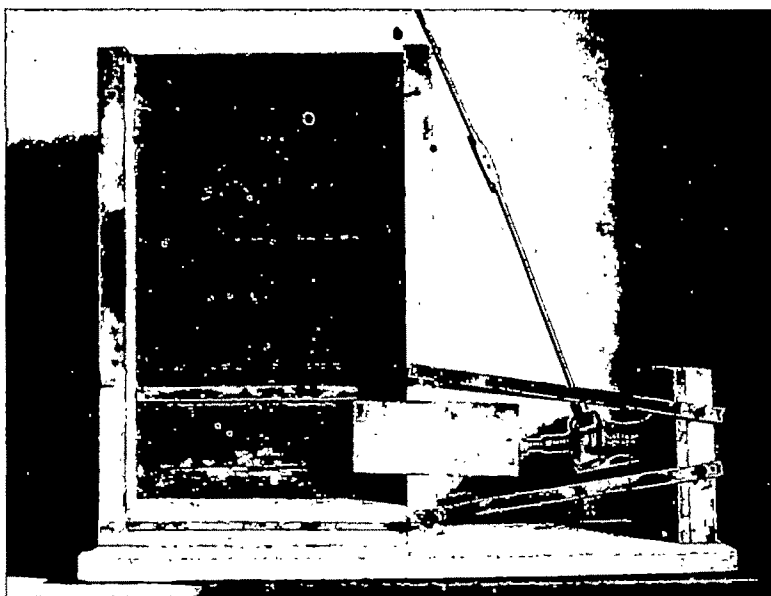


Fig. 1. Pressure box used in experiments. One side has been removed so as to show two of the separate floor boards in place.

EXPERIMENTS UTILIZING EVENLY DISTRIBUTED OVERBURDEN.

In the preliminary series of experiments where the plastic substratum was represented by an inflated rubber bag a syncline would form in almost every case just in front of the advancing piston (compare with Willis' anticlines), while at the same time an anticline would develop near the far end of the model. Upon further compression an overthrust or

⁹ Chamberlin, T. C., Jour. of Geol., 31, 499 and 503, 1923.

an overturned fold would usually develop from this syncline, the proximal end of the model (end nearest the piston) shearing out and over the trough of the subsiding syncline. A typical example taken from this series is shown in Fig. 2. At first it was thought that perhaps this structure was caused by the expansive force of the imprisoned air lifting the wax layers to form the anticline, so in all later experiments (unless

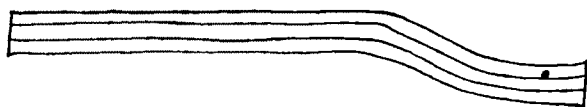


Fig. 2. Showing the development of a syncline near the piston, and of an anticline near the center of the model. The wax layers are resting directly upon an air-filled rubber bladder, and are being compressed from the right.

otherwise noted) the bag was replaced by an extremely plastic layer of modeling clay. In nine out of ten cases the results were as before, i.e., first a syncline would form, followed almost at once by the development of an anticline at a greater distance from the piston. In one case the anticline formed first. These anticlines and synclines were never as strongly developed as when the inflated bag was used, and overthrusts were much less frequent.



Fig. 3. Model similar to that shown in Fig. 2 but resting upon a plastic clay foundation which was not compressed with the model. Considerable crumpling has taken place at each end.

This would seem to indicate that greater plasticity of the substratum leads to the development of more pronounced folds, the bending strata more easily shouldering the more plastic material aside. A mashing and crumpling of the wax layers at one or both ends (usually the distal end) of the model was also of rather frequent occurrence, part of the thrust being absorbed in this fashion while, with the rubber bag in place, all of the thrust was taken up in flexing the layers. A model showing this mashing at the end farthest from the piston is

illustrated in Fig. 3. In all experiments of this series an evenly distributed load of about four inches of shot was used.

In four of the ten models well-developed underthrust structures were formed (both faults and folds), while in four others equally well-marked overthrust structures were seen. The remaining two models shortened chiefly by a confused crushing and crumpling at one or both ends; both over- and underthrusting being seen. In three trials wedge-shaped horst-like blocks bounded by reverse faults were driven upward, this phenomenon being found only near the proximal end of the model. Typical examples of these horsts are shown in Fig. 4. Horsts formed by compressive action do not seem

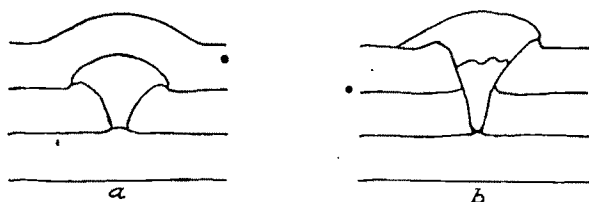


Fig. 4. Formation of horsts by compression. In *a* the upper and lower layers are of firm wax, the central one of softer material. The lower layer shortened by thrust-faulting farther to the left. Pressure from the right. In *b* all three layers are of firm wax. The lower layer again shortened by thrust-faulting. Pressure from the right.

to be recognized in nature, especially on a small scale, although various writers have suggested something of the kind in regard to large scale structural features in such ranges as the Rockies.¹⁰

This first series of experiments seems to indicate that if a substratum of sufficient plasticity to permit of vertical adjustments be present, (A) the fold which first develops on the side of the compressed zone nearest the active force is more likely to be synclinal than anticlinal in character; that (B) both under- and overthrust structures may develop under these conditions (they were in a 4:4 ratio in the experiments); and that (C) horst-like blocks bounded by reverse faults may be driven upward.

¹⁰ Shepard, F. P., Structural relations of the Purcell Range, . . , *Jour. of Geol.*, 32, 410, 1924.

Flint, R. F., Rocky Mountain structure, *Jour. of Geol.*, 32, 431, 1924.

Chamberlin, R. T., The wedge theory of diastrophism, *Jour. of Geol.*, 33, 772, 1925.

In all these experiments it was noted that there was a marked tendency for overthrusts to develop in the lower layers and underthrusts near the top whenever a considerable proportion of the compression had been taken up in crumpling and expanding the model in a vertical direction, especially when such action was concentrated near the distal end. Fig. 5 shows the distal end of one of the models after a compression of two inches. In this case it is obvious that the whole end of the model has expanded and thickened, the upper surface bulging upward and the lower surface downward, so that the still horizontal beds on the right have been forced against upwardly moving masses near the top of the column and against down-



Fig. 5. Section through the distal end of a model consisting of five thin layers of firm wax (black) separated by four of softer material. The whole model has thickened, the upper surface bulging upward, and the lower surface downward. There has been marked underthrusting in the upper layers and equally marked overthrusting in the lower. Pressure from the right.

wardly moving masses near the bottom. In other words, the underthrusts were produced where the resisting masses were moving upward, the overthrusts where they were moving downward. To investigate further this phase of thrusting a second series of experiments was devised.

EXPERIMENTS UTILIZING UPWARD-MOVING RESISTANCES.

The set-up used in this series is illustrated by Fig. 6-a. The clay substratum of the previous experiments was replaced by two loosely fitting blocks of wood "A" and "B" with a strip of plastic clay "C" between them. This assembly was placed upon the rigid floor of the pressure box, the usual wax models

laid upon them, and the whole column compressed in the usual manner under a load of five inches of shot. As the piston advanced it not only compressed the wax model, but, by driving block "B" before it, squeezed the mass of clay "C" upward into the overlying wax layers. Thus that portion of the model lying to the right of "C" was forced against an upward-moving mass of clay. Very decided underthrusts developed upon every repetition of this experiment. Fig. 6-b illustrates the results of a typical experiment of this series.

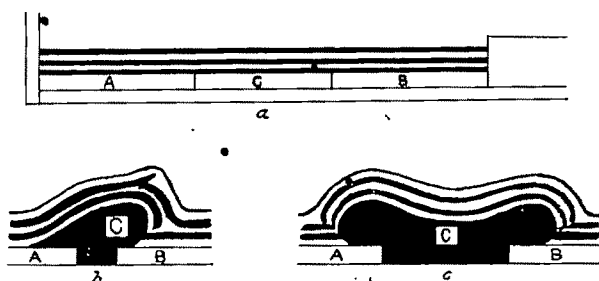


Fig. 6. a. Set-up used in second series of experiments. The wooden block "B" is free to slide over the floor of the pressure-box and, moved toward the left by the advancing piston, squeezes the clay "C" upward into the wax model.

b. Sketch on a slightly larger scale showing the results obtained by compressing the model shown above. The dark layers are firm and the white layers are soft wax.

c. Hypothetical double structure similar to that shown in b. Pressure is supposed to have been applied simultaneously from both sides. Note similarity to the Rocky Mountain-Wasatch type of structure.

The resemblance of this structure to that usually ascribed to the Front Ranges of the Rockies is striking, reverse faults dipping under the elevated region, massive intrusions, and a doming of the strata over the latter all being present. Had it been possible with the apparatus at hand to apply pressure to both ends of the model at the same time, a double structure, essentially like that shown in Fig. 6-c, would doubtlessly have been produced, a structure having what seems to be more than an accidental resemblance to the Rocky-Wasatch Mountain region. Of course, the essential features of the latter range are still a matter of dispute, but more than one investigator has been led to believe that the major thrusts of the Wasatch Mountains may dip toward the east, under the range. If this be true, the two lines of faults shown in the diagram would

correspond to the Willard and the Lewis "overthrusts" and their equivalents. Whether or not these mountains were actually formed in the way suggested, the experiments seem to show that such an origin is at least a possible one. The experiments seem to agree fairly well with the theories of such students of orogeny as Hobbs,¹¹ Flint,¹² Lawson,¹³ Chamberlin,¹⁴ and others who appear to agree on underthrusting as the most probable origin of this type of structure (although some of them avoid the use of the word "underthrust"), but differ somewhat among themselves as to the exact mechanism involved.

Since in mountain ranges of the folded type we frequently find a core of granitic material which has risen during, or closely approximating, the period of compression in much the same manner as the clay "intrusions" rose during the course of the experiments, it would seem that here we have a possible clue to the direction of the active forces during the folding process. In the case of a double mountain system it has been pointed out by more than one that one of only two possible processes must have taken place. Either there has been expansion from within the present limits of the mountains or else there has been compression from without. It is inconceivable that as much expansion as would be needed to cause the known folding could come from within so narrow an area. Expansion due to the rise of depressed isogeotherms, almost the only cause which may be invoked, is far too inadequate to produce the results which it is called upon to explain. The intrusion of batholiths into passive strata would seem more likely to produce tensional features across the tops of the resulting domes than compressional features along their flanks. One seems therefore driven to the conclusion that the forces were external to the region, and that any inward-dipping faults or folds must be under- rather than overthrusts. If the thrusts were transmitted across the region now occupied by the mountains, coming alternately from each side, and if the area farthest from the source of the compressive forces gave way, then overthrusts might be produced. This, while

¹¹ Hobbs, W. H., *Earth evolution and its facial expression*, p. 134.

¹² Flint, R. F., *Rocky Mountain structure*, Jour. of Geol., 32, 410, 1924.

¹³ Lawson, A. C., *Folded mountains and isostasy*, Bull. Geol. Soc. Am., 38,

253, 1927.

¹⁴ Chamberlin, R. T., *The wedge theory of diastrophism*, Jour. of Geol., 33, 772, 1925.

perhaps within the range of possibility, seems rather improbable.

Taking a hypothetical case for consideration, let us assume that an almost horizontal area covered with stratified rock is undergoing lateral compression. Early in the process the weakest portion (quite probably where the lens of sediments was thickest, since at this point the rigid or semi-rigid layer above the zone of flow would contain the greatest proportion of relatively weak sedimentaries) would begin to yield, the upper surface bulging upward causing erosion to become active at that point. Continued erosion would tend to remove this bulge, the column beneath rising through isostatic adjustments would as continuously tend to renew it, while the débris piled upon one or both flanks of the rising area would cause depression there. Thus, even before the regional compression was well under way, vertical movements of some magnitude would have started. The experiments of the second series seem to show that such vertical movements would, in the presence of tangential compression, be all that was needed for the production of underthrusts. Moreover, the active forces would in this case be directed from an area of less toward an area of greater overburden as measured upon the thrust plane¹⁵ and, as will be shown later on, this condition is very favorable for the development of overthrusts. If we assume that the initial elevation occurred near the center of the area of deposition and that the compressive forces were active (either simultaneously or alternately) on both sides of the compressed zone, then the development of a double mountain system flanked by underthrusts seems inevitable. If, on the contrary, the initial elevation occurred near the margin of the area of deposition, perhaps localized there by the lifting force of the still rising old-land from which the sediments were derived, then a single series of structures would develop along the foot of this old-land mass, and the prevailing dip of these structures needs must be into and under this ancient land. This would be equally true whether it had been overthrust upon the trough of sediments (active forces directed from the old-land) or whether the sediments had been thrust beneath it (forces directed toward the old-land). In neither case could the direction of prevailing dip tell much as to the direction from which these forces came, nor could the localization of the zone of most intense deformation be relied upon to give this informa-

¹⁵ This fact was first called to my attention by Prof. J. H. Swartz.

tion since this zone would almost certainly be located near the line separating the rising and sinking crustal blocks. It would be here that the once level sediments would be most deflected from their original attitude practically parallel to the plane of the thrust and hence it would be here that they would be least competent to transmit this thrust.

EXPERIMENTS UTILIZING A NON-UNIFORM DISTRIBUTION OF
OVERBURDEN.

A third series of experiments was designed to test the influence of a non-uniform distribution of overburden upon the character of the structures developed beneath it. Forty individual experiments were run, the models in each case consisting of a thin and brittle layer of plaster intercalated between two thicker and more plastic layers of wax. This particular

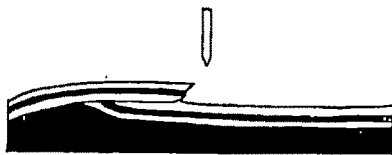


Fig. 7. Underthrust fault which developed in a model consisting of two layers of wax (white) with a brittle layer of plaster between them. That portion of the model lying to the right of the partition shown near the center of the drawing supported four inches of lead shot during compression while the portion to the left of the partition supported eight inches. Pressure from the right.

arrangement was chosen in order to ensure the development of faults rather than of folds, preliminary experiments having shown that more decisive and clear-cut results could be obtained in the former case. For this series the pressure box was supplied with a thin-edged partition reaching to within two inches of the upper surface of the models and the overburden of shot was piled to different depths upon the two sides of this partition. In twenty cases the greatest weight was placed upon the distal and in twenty cases upon the proximal end of the model. Each group of twenty experiments thus defined was further subdivided into two groups, ten in which a plastic substratum was used and ten in which it was omitted. Fig. 7 shows a typical experiment of this series, in this case the greater weight being upon the distal (left-hand end) of the model, which rests upon a plastic foundation.

A peculiar type of "mixed thrust" developed in a number of cases, an example being given in Fig. 8. In these cases the upper wax and the plaster layer usually developed well marked underthrusts, the lower wax layer at the same time developing equally well marked overthrusts. This type of structure was noted ten times during the forty trials, eight times when the greater weight lay upon the distal end of the model, and twice when it lay upon the proximal end. In six cases the plastic foundation was absent, and in four it was present. Although such structures seem rather improbable, it would be difficult to recognize them in nature, for with a slight amount of erosion a simple thrust hading in one direction would be uncovered, and with further erosion an equally simple one hading in the opposite direction would appear. Or, should both portions of the thrust chance to be uncovered, it would



Fig. 8. Model similar to that shown in Fig. 7 but which developed a fault of the "mixed-thrust" type. Pressure from the right.

still be very easy to interpret them as two independent faults. It seems rather probable, however, that such mixed thrusts are rare or non-existent, and were here developed simply in response to some condition inherent in the pressure box.

Regarding the relative frequency with which over- and underthrusts developed, some interesting comparisons can be made. Considering a "mixed thrust" to be the equivalent of one over- and one underthrust, the percentages exhibited in the following table were computed to the nearest whole number.

	GREATEST OVERBURDEN PROXIMAL		GREATEST OVERBURDEN DISTAL	
	Plastic base	No plastic base	Plastic base	No plastic base
Overthrusts	55%	44%	33%	63%
Underthrusts	45%	56%	67%	37%

It is interesting to note that in both groups the removal of the plastic clay substratum almost exactly reversed the percentages of over- and underthrusts obtained. Also, if we assume that the presence of this plastic substratum more nearly repre-

sents natural conditions, and if we further assume that the compressive forces came from the direction of the most heavily loaded areas, then it would appear that there should be slight excess of *over-thrust* structures beyond those which are *under-thrust* in character. If, on the contrary, we assume that the compressive forces came from the region in which the less heavily loaded areas lay, we find that a still greater (numerical) excess of *underthrusts* is to be expected.

It must be remembered in connection with this point that areas which are sinking under the weight of accumulating sediments are not especially heavily loaded at the depths where thrusting must take place. If we consider two adjacent land masses in isostatic equilibrium, one sinking under an accumulation of sediments and the other rising through erosional relief, we find that it is only at the "level of compensation" that they exert the same downward pressure per unit area. At any depth less than the level of compensation the higher (rising) mass will exert a greater pressure than the lower (sinking) area since a lesser proportion of its total mass lies below the plane upon which the weight is being measured.¹⁸ Since all thrusts must take place above the level of compensation, the weight upon any given thrust plane must be measured not by the amount of accumulated sediments, but by the elevation of the areas concerned above the level of compensation and by the elevation of the thrust plane itself above this level.

Granted then that elevated areas produce the greatest burden upon a thrust plane, and remembering that the second series of experiments indicated that underthrusts are to be expected when the resisting masses are moving upward, it appears that lateral pressure applied to the flanks of a rising area could not but produce underthrusts. In the case of the Rocky Mountain area we seem to have present the two factors most favorable to the development of underthrusts, for, as has been pointed out by more than one, the compressive forces were almost certainly external and directed inwardly toward the axis of the rising mountains, which at the same time by virtue of their elevation (due to isostatic adjustment) formed an excess burden upon the thrust planes. In the case of the Appalachians where the direction from which the deforming forces came is much less

¹⁸ That is, assuming a not too heterogeneous distribution of density with depth. The argument holds either if we assume a constant density or a regular increase with depth, but might break down if, as might be true in special cases, the heavier masses lay close to the surface.

evident, the experimental work would point to overthrusts if these forces came from the east, and to underthrusts if they came from the west, and is in perfect accord with the prevailing dip of Appalachian structures.

One further fact emerges from the data given in the table above: an unequal distribution of load will, if other conditions be favorable, render the development of underthrusts more probable. In the first series of experiments, where an equally distributed overburden and a plastic substratum were both present, the ratio of under- to overthrusts was 1 : 1, while in the third series, in the comparable case where a clay base was also used, we find that if the character of this unequal loading be neglected this ratio rises to slightly over 3 : 2 and under the most favorable conditions (greatest load distal) reaches 2 : 1.

THE POSSIBILITY OF LARGE-SCALE UNDERTHRUSTS.

In cases where the field evidence is inconclusive as to whether a mass of crystalline rock has been overthrust upon sedimentaries or whether the latter have been underthrust into and under the former, it has been objected that the second interpretation is untenable because of the inability of the weaker material thus to penetrate the stronger.¹⁷ The authors of this type of criticism doubtless have in mind a case somewhat analogous to a wedge of wood being driven into a block of metal: but how if the wedge be tipped with metal and only the haft be made of wood? And what is the essential difference between a wedge driven into a block and a block driven upon a wedge? Consider such a region as is shown in Fig. 9-a, a mass of crystallines somewhat elevated above the general level on the left and depressed upon the right. Erosional forces are removing material from the more elevated portions of the region and depositing it in large part upon the more depressed areas. The disturbance in balance thus brought about will cause isostatic forces to come into play, the left-hand mass rising almost as fast as it is eroded, the right-hand area meanwhile as steadily sinking. Let us further assume that there is at the same time compression of the region, the active forces coming from the right. Under these circumstances the forces of this tangential compression and the vertical stresses due to isostatic adjustment will combine according

¹⁷ Keith, A., Outline of Appalachian structure, Bull. Geol. Soc. Am., 34, 336, 1923.

to the familiar "parallelogram of forces" and two resultant forces may be thought of as existing in the neighborhood of the line "A—B." These forces will tend to force the left-hand block upward and to the right, and the right-hand block downward and to the left. These "resultant" forces are shown in the diagram by the dot-and-dash arrows and their

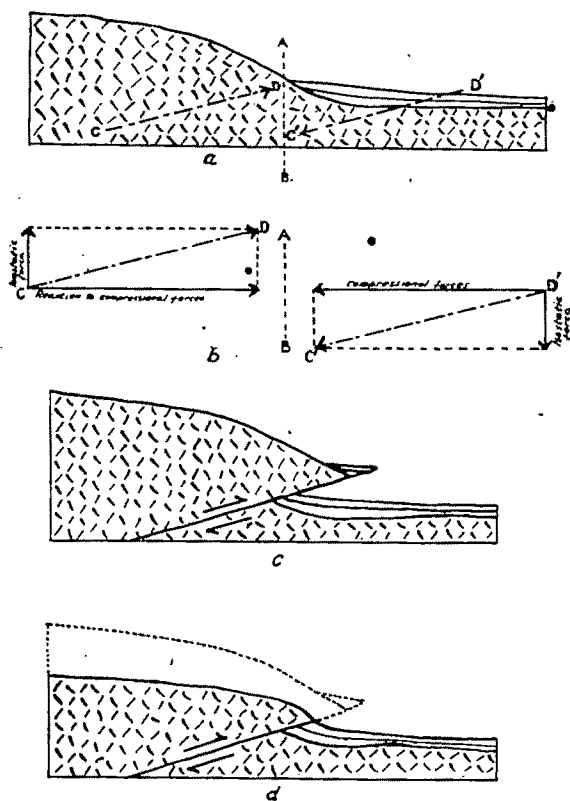


Fig. 9. Showing the development of underthrusts along the contact of sedimentaries and crystallines by the combined action of tangential compression and isostasy. Pressure is assumed to be coming from the right.

origin is more clearly indicated in the purely schematic diagram of Fig. 9-b. They would clearly produce a shearing stress parallel to "C—D" and "C'—D'" and should this shear develop into a zone of faulting the conditions shown in Fig. 9-c would ensue, the low-lying mass of crystallines having now been forced downward and beneath the mass of the left. It

is to be noted that the sedimentaries carried upon the down-faulted block have not forced their way into and beneath a mass of firmer material, but have been carried there more or less passively by the mass of crystallines upon which they lie, these latter having borne the brunt of the transmission of stress as well as the greater part of the frictional resistance along the fault surface. As Lawson¹⁸ has pointed out, the deeper the competent crystallines below the sedimentaries are depressed into the zone of flow the less competent they become to transmit thrusts. This would seem to the writer to mean that any large scale thrusting must take place before this competent horizon has been too thinned to transmit the required stresses. After faulting has occurred (or rather while it is going on) erosion would reduce the region to the condition shown in the last diagram of the series, and one would be faced with the apparent anomaly of a wedge of soft sediments driven into and under a mass of firmer crystallines. Of course, had the active pressures come from the left instead of from the right, an overthrust indistinguishable from the underthrust whose development has just been followed would have been produced.

Thus it seems that, while they may not necessarily occur, there are no mechanical reasons why underthrusts could not be formed along the contact of sedimentaries and crystallines provided the forces acting upon the region were of the requisite character.

Should a thrust fault not develop, but the arc under compression be shortened by folding, then a similar line of argument will apply, the only essential difference between the two cases being that now the thrust would be replaced by a fold, the axial plane of the latter dipping in the same direction, though perhaps not at the same angle, as the thrust plane which it replaces.

SUMMARY AND CONCLUSIONS.

In conclusion, the writer wishes to emphasize the point that he is not attempting to show that the majority of faults and folds are under- rather than overthrust in character, nor indeed that any of them are necessarily so. The object of this study was primarily for the purpose of determining under what con-

¹⁸ Lawson, A. C., Folded mountains and isostasy, *Bull. Geol. Soc. Am.*, 38, 261, 1927.

ditions such underthrusts might develop. The conditions which appear favorable for the development of underthrusts seem to be matched fairly well by the conditions under which the Rocky Mountain area was deformed, but this of course is not to be taken as proof that the major structures of this region are underthrust in character, but merely as indicating the possibility that they may be so. In none of the experimental work were any criteria discovered by means of which under- and overthrusts might be distinguished by an examination of the structures themselves. The law propounded by Newton that "action and reaction are equal" unfortunately is as true in problems of crustal deformation as in any other field, and lacking some fixed and unmoving point of reference the determination of the actual, as distinguished from the relative, movement during deformation remains in the most part an unsolved problem. . .

It would appear that the following conclusions may be drawn from the experiments described in this paper:

Underthrusts are favored by great plasticity of the substratum, upward-moving resistances, and unequal distribution of overburden, the latter being especially effective when the greater weight lies upon the side of the compressed zone farthest from the point at which the active pressure is applied. Overthrust structures are favored by the contrary of these conditions, that is, slight plasticity of the substratum, downward-moving resistances, equal distribution of overburden or, if the latter have an unequal distribution, by the greater weight lying upon the side of the compressed zone nearest the point of application of the active forces. With no plastic substratum present the effects of unequally distributed overburden are reversed, underthrusts then being favored by the greater weight lying near the point where tangential pressure is applied and overthrusts by this excess weight being on the side of the compressed zone farthest from this point. It further appears that when these conditions are applied to the Rocky Mountain and Appalachian regions a fairly good case for underthrusting can be made for the former mountains, while for the latter the problem still remains indeterminate.

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THE HYDRATES, TRANSITION TEMPERATURES AND SOLUBILITY OF SODIUM IODATE.

H. W. FOOTE AND JOHN E. VANCE.

Contribution from the Department of Chemistry, Yale University.

Sodium iodate has been reported by various investigators as forming, from water solution, no less than seven hydrates, besides the anhydrous salt.¹ No investigation along modern lines has been carried out to determine the stable hydrates, their transition temperatures and solubility. In the present investigation this data has been obtained between the freezing point of the saturated solution and about 90°. No stable hydrate exists above 73.4°.

Material and Method of Analysis. The sodium iodate used was a very pure commercial product having a composition closely approximating the monohydrate. It was recrystallized before use. In the analysis of solutions and residues, iodate was determined by adding to the solution an excess of potassium iodide, acidifying with sulphuric acid and titrating with standard sodium thiosulphate solution. When more convenient, the water (instead of the iodate) in a solid residue could be determined by heating at 120-140°. The iodate is entirely stable at the latter temperature.

Transition Temperatures. Preliminary determinations by means of cooling curves (between 25° and the eutectic temperature) and dilatometer observations (between 5° and 95°) indicated only two transition temperatures, one slightly below 20° and the other below 90°. The change of the unstable into the stable form immediately above and below the higher transition temperature is exceedingly slow, and for this reason we were unable to determine this temperature accurately either by the dilatometer or by a cooling curve. The slowness of transformation, however, rendered it possible to determine the solubility of the two forms concerned, both above and below the transition point, thus obtaining metastable as well as stable systems. The solubility curves are fortunately quite different in slope and the intersection gives the transition temperature 73.4° with considerable accuracy (see Fig. 1). The solid phases in equilibrium at this temperature are $\text{NaIO}_3 \cdot \text{H}_2\text{O}$ and NaIO_3 .

¹ For a review of the literature on the subject see, for instance, Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, Vol. 2, p. 334.

The solid phases at the lower transition temperature are $\text{NaIO}_3 \cdot \text{H}_2\text{O}$ and $\text{NaIO}_3 \cdot 5\text{H}_2\text{O}$. They transform into each other very readily. This temperature was determined by (1) a thermal method, (2) by the dilatometer, and (3) by the solubilities. By the first method, nearly equal weights of the two hydrates were mixed with a solution already saturated at approximately the right temperature and placed in a vacuum-jacketed flask. Due to the heat of transformation, the system adjusts itself at the transition temperature. Approaching this temperature from above and below, the values 19.7° and 19.55° were obtained. By means of the dilatometer, the value 19.85° was obtained. From the solubility results which are given below, the value 20.3° can be derived. The average of all four determinations is 19.85° .

Hydrates. In principle, the determination of all the stable hydrates of a salt is exceedingly simple when the transition temperatures are known. All that is necessary is to allow the salt to crystallize at a temperature within its stable range, and determine its composition.

Two samples of the hydrate which is stable below 19.85° were obtained by crystallization below this temperature. They were removed from solution and dried quickly in a cold room. Analyses gave 68.58 and 68.68 per cent of NaIO_3 . The compound $\text{NaIO}_3 \cdot 5\text{H}_2\text{O}$ contains 68.72 per cent of NaIO_3 .

Numerous analyses of the monohydrate, which was found to be the only stable hydrate above 19.85° , were made on samples obtained from solutions at various temperatures within the stability range of this hydrate. This was done because of the other hydrates, particularly the compound $\text{NaIO}_3 \cdot 1\frac{1}{2}\text{H}_2\text{O}$, which are mentioned in the literature.² While the dilatometer showed no irregular expansion throughout the range between 19.85° and 73.4° , indicating that no transition occurred, it seemed highly desirable to show by analysis that only one form, the monohydrate, existed. In some cases, the solid residue from a solubility determination was used for analysis. In others, the salt was allowed to crystallize from solution at the temperature indicated. Averages of closely agreeing results at each temperature were as follows:

Temperature:	20°	25°	30°	35°	40°	60°
Percent NaIO_3 :	91.71*	91.70†	91.76†	91.34*	91.81*	91.91†

* From a solubility residue.

† By slow crystallization.

² Meerburg (Z. anorg. Chem. 45, 324 (1905) assumed this hydrate was the stable form at 30° in investigating the system $\text{NaIO}_3\text{-HIO}_3\text{-H}_2\text{O}$.

The calculated percentage of NaIO_3 in the compounds $\text{NaIO}_3 \cdot \text{H}_2\text{O}$ and $\text{NaIO}_3 \cdot 1\frac{1}{2}\text{H}_2\text{O}$ are 91.65 and 87.89 respectively. The results appear to be quite sufficient to show that only the former exists.

To determine when the anhydrous salt was present in the solubility determinations at the higher temperatures, the solid was filtered on a warm Gooch crucible, washed quickly with alcohol and dried between filter papers. This method of obtaining the solid gave entirely satisfactory results as the change from monohydrate to the anhydrous salt (and the reverse) is slow. The residues were either analyzed or tested in a closed tube for water.

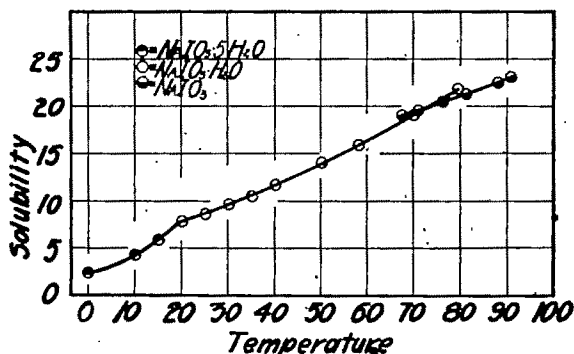
Solubility. The solubility was determined in duplicate at each temperature chosen, approaching equilibrium from (1) supersaturated and (2) undersaturated solutions. The mixtures were shaken in a thermostat from four to six hours. Constant solubility, within narrow limits, showed that equilibrium had been reached. The usual precautions were adopted in removing samples for analysis. Following are the results:

SOLUBILITY OF SODIUM IODATE.				
Temperature	Grms. NaIO_3 in 100 gms. Solution.		Average	Solid Phase
	I.	II		
0.0°	2.39	2.46	2.42	$\text{NaIO}_3 \cdot 5\text{H}_2\text{O}$
10.0	4.39	4.40	4.39	" "
15.0	5.87	5.88	5.88	" "
20.0	7.87	7.82	7.84	$\text{NaIO}_3 \cdot 1\frac{1}{2}\text{H}_2\text{O}$
25.0	8.65	8.66	8.66	" "
30.0	9.63	9.63	9.63	" "
35.0	10.58	10.55	10.57	" "
40.0	11.70	11.71	11.71	" "
49.9	14.13	13.99	14.06	" "
57.8	15.97	15.86	15.91	" "
69.6	19.05	19.00	19.03	" "
79.0*	21.91	21.74	21.82	" "
67.0*	18.98	19.10	19.04	NaIO_3
70.6*	19.55	19.57	19.56	"
75.8	20.48	20.49	20.49	"
80.6	21.22	21.26	21.24	"
87.6	22.12	22.32	22.22	"
90.3	23.02	23.03	23.03	"

* Metastable system.

The average results have been plotted in the diagram, Fig. 1. In Fig. 2 the logarithm of the solubility has been plotted against $1000/T$, where T is the absolute temperature. As

might be expected, the results for the pentahydrate and the anhydrous salt fall very nearly on a straight line, as the temperature range in each case is small. The linear relation for the



•Fig. 1.

monohydrate is evident between 20° and 50° but the results diverge somewhat above this temperature. This may be shown also by calculating the solubility from the equation of

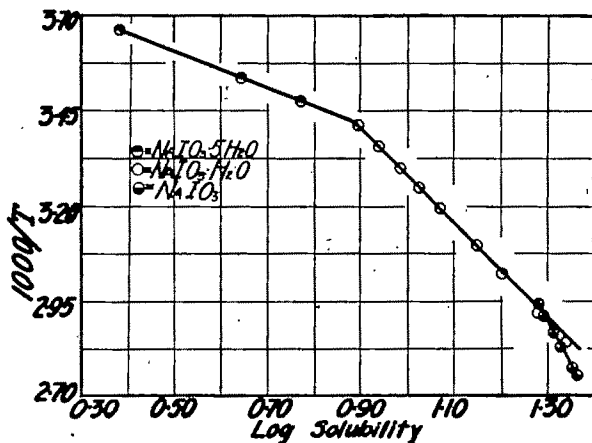


Fig. 2.

the straight line between the points at 20° and 49.9°. This equation is the following:

$$\log \text{ solubility} = 3.6344 - \frac{802.8}{T} \quad (1)$$

By means of this equation, we have calculated the solubility of the monohydrate at the temperatures where the solubility

was determined. The following table gives a comparison between the calculated and observed values:

Temperature	Solubility (Calculated)	Solubility (Determined)	Difference
20°	(7.84)	7.84	..
25	8.71	8.66	.05
30	9.66	9.63	.03
35	10.66	10.57	.09
40	11.73	11.71	.02
49.9	(14.06)	14.06	..
57.8	16.13	15.91	.22
69.6	19.55	19.03	.52
79.9	22.58	21.82	.76

The corresponding equation for the solubility of the pentahydrate, based on the results at 0° and 15°, is:

$$\log \text{solubility} = 7.7793 - \frac{2019}{T} \quad (2)$$

The transition temperature calculated from these two equations is 20.3°, which is the value mentioned previously under transition temperatures as calculated from the solubility. The higher transition temperature, 73.4°, is taken directly from the plotted solubility results, as the logarithmic relation for the monohydrate at the higher temperatures is not a straight line.

The freezing point of the saturated solution is -0.35°. The solubility at this temperature has been calculated from equation (2). The solubility at 19.85°, the lower transition temperature, is calculated from equation (1), while the corresponding value for the higher transition temperature 73.4° has been taken directly from the plotted results.

The results are as follows:

	Percent of NaIO ₃ in solution	Solid Phases
-0.35°	2.38	Ice and NaIO ₃ ·5H ₂ O
19.85°	7.83	NaIO ₃ ·5H ₂ O and NaIO ₃ ·H ₂ O
73.4°	20.00	NaIO ₃ ·H ₂ O and NaIO ₃

SUMMARY.

1. The stable hydrates of sodium iodate are NaIO₃·5H₂O and NaIO₃·H₂O.
2. The two transition temperatures in the system occur at 19.85° where NaIO₃·5H₂O and NaIO₃·H₂O are in equilibrium, and at 73.4°, where NaIO₃·H₂O and NaIO₃ are in equilibrium.
3. The solubility of sodium iodate has been determined between 0° and 90.3°.

STERLING CHEMISTRY LABORATORY,
YALE UNIVERSITY,
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DISCUSSION AND COMMUNICATIONS.

MAP PROJECTIONS AND NOMENCLATURE.

The Nordisk Varlds Atlas by S. Zetterstrand and Karl D. P. Rosén, Stockholm, 1926, brings rather strikingly to our attention the advances that have been made in recent years in mathematical cartography and nomenclature.

In the preparation of world atlases, the occasional use of systems of projection designed solely for nautical charts has created erroneous impressions in the relative size of land masses. It is with this viewpoint of deficiencies in geographical representation that the authors of the new atlas have departed from former methods and have placed *every map* in their folio upon an equal-area representation. In simple language, the latter term implies that any portion of the map bears the same ratio to the region represented by it that any other portion does to its corresponding region; thus, in a map of the world, a coin placed on South America will cover the same area as the same coin placed upon Greenland.

The failure of the Mercator conformal projection employed in nautical charts to meet this requirement is obvious.

In his map of Europe, Prof. Rosén employs the Albers equal-area projection with two standard parallels. This is the same projection which the Board of Surveys and Maps at Washington, D. C., authorized the U. S. Coast and Geodetic Survey to prepare for a new map of the United States on a large scale to supersede the present wall maps issued by the several departments of the government. The maps will embody the latest information as to surveys and other geographic detail. The work of the Coast and Geodetic Survey having ended with the construction of the projection and compilation of shoreline, the completion of the map in all its detail is being carried on by the U. S. Geological Survey. The scale of the new wall map when published will be 1:2,500,000 and the size will be the same as the present issue. The chief advantage of this projection in addition to straight meridians and equal-area representation, will be a reduction of scale error from a maximum of 7 per cent in the present issue to $1\frac{1}{4}$ per cent in the new map. Even in the vicinity of New York the present wall map has a scale error of more than 4 per cent.

Besides the two standard parallels of true scale, there are in the Albers projection at any point two diagonal lines or curves of true length scale, approximately at right angles to each other, termed isoperimetric curves. The projection thus offers more true scale properties than any other system of mapping for countries of predominating east and west extent. It follows also

from its equal-area properties that measurements in different parts of the map, planimetric or otherwise, can be directly compared.

World Mapping.—In the solution of that most difficult problem of equal-area world mapping, Prof. Rosén employs the so-called sinusoidal projection which is also an equal-area representation. The map appears in three tangential alignments: North and South America, Europe and Africa, Asia and Australia. The maps are artistically finished and tinted, and are employed in the atlas for various statistical world comparisons.

This same system of projection is employed by the Bureau of Foreign and Domestic Commerce, Washington, D. C., for purposes of statistical comparisons, such as population densities, natural resources, etc. The arrangement employed by the American bureau is slightly different and better than that of Prof. Rosén's, due to the fact that this system of projection adapts itself to an interrupted alignment as between the northern and southern continents. Whereas in Prof. Rosén's arrangement we have three vertical groupings, in the Bureau's, we have the benefit of five or six orientations to the north and south.

In connection with the term sinusoidal as applied to the name of this projection, due credit should be given to Mercator's son who employed it in his atlases as early as 1606-7-8-9. Much of the odium reflected in the misappropriation of Mercator's conformal projection (as used in nautical charts) to the mapping of areas of large latitudinal extent, should be applied to geographers themselves rather than to the renowned inventor, Gerhard Krämer, better known by his Latin surname Mercator.

That Mercator devised and used this equal-area projection evidences his appreciation of mass representation as regards relativity in contradistinction to conformality in his nautical projection. The projection was subsequently called the Sanson-Flamsteed and, later on, the sinusoidal projection. Sanson did not use it, however, until 1650, over 40 years after Mercator. Flamsteed used it first in 1729. This same system of equal-area network has also found its usefulness in industrial science and is utilized by the General Electric Company in the Illuminating Engineering Laboratory.

In addition to the above types of equal-area representation, Prof. Rosén has devised several systems of his own, of which his transverse intersecting cylindrical equal-area projection for North America, South America, and Africa is worthy of study and comparison with other systems. In the matter of hemispherical equal-area representation, he has extended the Lambert meridional projection from 180 degrees of longitude to 200 degrees, thus giving overlaps instead of tangential junctions.

In connection with the adoption by the International Map Committee, London, 1909, of a suitable map projection of the world,

1:1,000,000, we find Prof. Rosén among the critics as to the efficiency and scientific value of the system which was pressed upon the Committee. As other eminent cartographers have taken this same viewpoint, it is needless to open up the controversy of which a recent exposition is found in Lomnicki's article published in Lwow, Poland, 1927.

Nomenclature.—On the subject of nomenclature, the authors of the World Atlas should be commended for their adoption, in the spelling of cities of foreign countries, of the usage prevailing in the countries themselves. We also find that Rand, McNally & Company have recently applied the same system as far as Roman letters will permit. Thus, the familiar names Rome, Florence, Venice, Leghorn, and Vienna are now mapped as Roma, Firenze, Venezia, Livorno and Wien, with the more familiar name appearing parenthetically under the real name. The system is most useful in the postal service, in commerce, and to the tourist, regardless of the foothold the old names have obtained in history and general English literature.

The World Atlas, thus briefly reviewed, is carefully and neatly compiled, unusual attention having been given to projection control, fine quality of paper, and neat color schemes. Its dimensions are 10 x 15½ inches and the work consists of 50 double-page maps + 96 pp. + 40 pp. of descriptive and illustrated text. The maps of the continents include bathymetric curves with gradations of color for sub-oceanic relief. The Atlas was published for the benefit of the Swedish Red Cross. Its preparation was sponsored by Prince Carl, chairman of the Swedish Red Cross Society, and by various firms and individuals who contributed to make the publication possible.

CHARLES H. DEETZ.

U. S. COAST AND GEODETIC SURVEY,
WASHINGTON, D. C.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Qualitative Analysis; by WILLIAM WARDLAW and FREDERIC W. PINKARD. Pp. vii, 166. London and New York, 1928 (Longmans, Green and Co., \$1.25).—The first thing in this text which attracted our attention was the statement in the introduction to the effect that reactions and equations would not be dealt with from the standpoint of the ionic theory. The authors have lived up to this specification surprisingly. A reasonably diligent search revealed only four pages of the text where a few ions had crept in, probably unbeknown to the authors. These ions were not doing anything in particular and appeared lonesome. To be sure, the authors expect that the majority of students for whom the text was designed will not have heard of an ion, but if so, we feel they should postpone the pleasure of a course in qualitative analysis until they have had some contact with the researches of Arrhenius.

Aside from the above omission, the text is very good. Rather more space is devoted to dry reactions and blow-pipe tests than is usual in most texts of this caliber. Some good elementary chemistry is studied along with the analytical methods, and notes on the analyses are plentiful and pertinent. The procedure itself is simple and sound. We note that the acids are classified according to their behavior with dilute and with concentrated sulphuric acid. This departs from the usual classification, but we believe it will teach a beginner more chemistry than would the "standard" method of sorting into groups.

In closing, we cannot help noting the fact that two different formulas are used for the basic ferric acetate molecule in different sections of the text. We were also never sure which one to use.

E. B. KELSEY.

Acetate Silk and Its Dyes; by CHAS. E. MULLIN. Pp. 473, 13 figs. New York, 1927 (D. VanNostrand Co., \$6.00).—The cellulose acetate silks have found extensive use since the apparently successful solution of many of the problems connected with the dyeing of these fabrics. On this account a book dealing with their preparation and properties serves a very useful purpose.

The book is largely a compilation of the work of other investigators, but as such serves to give an excellent breadth of view of the subject. The preparation and properties of the cellulose acetates, together with a chapter on identification of Rayons, are presented in the first hundred pages. The treatment is distinctly chemical and it is apparently not the purpose of the author to give a description of the mechanical operations involved in the manu-

facture of the fibers. The larger portion of the book is devoted to a survey of methods of dyeing, with emphasis on the types of dyes which have met with success. This is a feature of the book which should commend it to those who are interested in the many problems connected with the dyeing of cellulose acetate silk.

A. J. HILL.

Experiments on Auto-Electronic Discharge.—The fact that electrons could be drawn from a cold cathode if subjected to a sufficiently intense field was established by Lilienfeld in 1923. The resulting flow which may be of the order of some micro-amperes has been termed the auto-electronic current. Its dependence upon accompanying conditions such as the presence of a residual gas has been both asserted and denied by different investigators.

A form of apparatus recently devised by N. A. DE BRUYNE to test this matter appears to decide definitely against such presence as an inducing cause of the phenomenon. The essential feature of the apparatus was a clean tungsten cathode prepared by melting off or burning out a tungsten filament so that it projected into a concentric nickel cylinder which served as anode. These electrodes properly supported were enclosed in a glass bulb which could be filled with various gases and evacuated. The discharge current was then measured for a selected pressure as the voltage was increased by steps between 5,000 and 15,000 volts.

For both air and hydrogen the current and the rate of rise was much larger at a low pressure (10^{-6} mm.) than at a higher (10^{-3} mm.). The conclusion is unescapable that the residual gas retards the phenomenon and cannot be regarded as the main or even a contributing cause.

In order to test the effect of the material of the cathode, or at least the nature of its surface, the filament was altered by the deposition of barium ions from a glow discharge. A repetition of the preceding method of observation showed that the barium treatment had greatly increased the discharge, indicating that auto-electronic currents depend upon the nature of the cathode in somewhat the same way as thermionic emission does, but with this notable difference, that the former are almost independent of the temperature, while the latter varies rapidly with it. *Phil. Mag.* 5, 574, 1928.

F. E. B.

Probability and its Engineering Uses. by THORNTON C. FRY. Pp. xiv, 476; 49 figs. New York, 1928 (D. Van Nostrand Company, \$7.50).—Some branches of mathematics seem to develop smoothly and in an orderly way from a few simple assumptions, as e. g. the theory of potential, or of image formation in optics, until progress is stopped by the increasing complexity of the analysis; but the mathematics of discrete quantities as, for instance, the theory of probability with its various ramifications into probability *a posteriori*, expectation, fluctuations and correla-

tion is not of this kind. Probability, or more specifically its measure, is not easily defined and statements about it have to be hedged with postulates, and axioms or conventions, and often the different problems seem to be each in a class by itself.

The present book by a mathematician engaged in industrial work (The Bell Telephone Laboratories) forms both an interesting and valuable contribution to the literature of the subject. Nine chapters are used, so to speak, in clearing the trail and cutting steps over the slippery places. Many instructive problems are worked out and theorems derived. The discussion of distribution laws seems unusually good. The aim of the book is particularly to show the engineering uses of probability and those matters which are specially characteristic of the book are contained in the chapters which treat the distribution functions of most frequent occurrence in engineering and the theory of probability as applied to problems of congestion. Another chapter of applications is given to the kinetic theory of gases and other statistical phenomena which arise in physical investigations.

The book has great merit and should be possessed by any student desiring a thorough acquaintance with the theory of probability; and furthermore, it is too much to hope, but not to wish, that every person calling himself a statistician should be required to pass an examination on this book.

F. E. B.

Matter, Electricity and Energy; by WALTER GERLACH. Pp. xii, 427; 119 figs. New York, 1928 (D. Van Nostrand Company, \$6.00).—It should be remarked in the first place that this book is wholly devoted to the properties of the atom, a fact which is not clearly set forth in the title. It first appeared in German in 1923 and met with so favorable a reception as a text for graduate seminar work that a second and revised edition was required in 1926. It is this latter edition which now appears in an English translation by Francis J. Fuchs. It will be found especially serviceable for all students of science who desire to learn what has been discovered concerning the structure of the atom and the laws of the forces which are operative both within and without the atom. While they are closely related and interdependent each chapter is virtually a lecture, complete in itself, upon some particular phase of the subject. The titles of the chapters are too numerous to quote in full but a mention of some of the topics will give an idea of its scope; viz., Isotopy, Molecular Dipoles, Nuclear Disintegration, The Magnetron, Superconduction, Spectral Emissions of various kinds, The Photo-electric Effect, Structure Analysis, and Resonance and Dispersion.

As the purpose of the author is to stimulate the student and ground him in the fundamentals necessary for subsequent study the book can hardly be classed as a popular work but it is perhaps as simple and non-technical a presentation as can be made. A

certain amount of mathematical formulation was unavoidable but nothing which will greatly impede the reader who desires a real insight into the problems of modern physics.

F. E. B.

Das Wesen der Materie und der Aufbau der Atome; by G. WEBER. Pp. 148; with figs. Leipzig, 1927 (Verlag Otto Hillmann).—This is a book of metaphysical import in which, to quote the author, "the attempt is made to derive both the ultimate elements (Urstoffe) and their finite properties immediately from the infinite and thus find the key by which a simple, unique and unobjectionable derivation is possible for the general laws covering the experimental facts and phenomena of physics and chemistry." In the course of this discussion the author traverses most of the field of physics, Atoms, States of Matter, Radiation, Electricity, Gravitation, Atomic Disintegration, Chemical Combination, The Periodic System, etc.

It looks like a safe guess to say that the general reader will leave this exposition to the philosophers to break their teeth upon.

F. E. B.

GEOLOGY.

North America; by I. C. RUSSELL (1852-1906). Second edition, pp. 435, 39 figs., 7 colored maps. New York, 1927 (Oxford University Press, American Branch), \$4.25.—The first edition of this valuable book appeared in 1904, and it gave, as was the expressed hope of its author, a readable account of the salient geographic facts concerning North America. In this new edition only the chapter on geology has been brought up to date, which has been most acceptably rewritten by Dr. Arthur Holmes of the University of Durham, England. It is regrettable that the publishers have failed to have had the other chapters modernized and the bibliographies appended to them brought up to date.

ADOLPH KNOPF.

Studies in the outlets of Ancylus Lake (Swedish with English résumé); by HENRIK MUNTHER. Sveriges Geol. Undersökning, Ser. C, No. 346 (Årsbok 21, 1927, No. 1). Pp. 107, 4 pls., 57 text-figs., Stockholm, 1927.

The Geological Age of the Svea River. A pollen-analytical study in Ancylus-time geography. Appendix: The Göta River in Ancylus-time; by LENNART VON POST. Sveriges Geol. Undersökning, Ser. C, No. 347 (Årsbok 21, 1927, No. 2). Pp. 132, 2 pls., 24 text-figs., Stockholm, 1928.—When the retreating border of the last Scandinavian ice sheet stood in central Dalarna, the land upheaval had brought the lowest parts of the watershed south of Degerfors in Närke (east of the northern end of Lake Vänern) to the then sea-level, and the Baltic became a lake—Ancylus Lake. The first main outlets of Ancylus Lake were across the watershed

just mentioned, and are marked by impressive erosional phenomena, for the water masses may have been greater than those passing over the Niagara Falls. The thresholds now stand at altitudes of 105 to 110 meters, and the Ancyclus shore at the outlets stands at elevations of 113 to 115 m.

Because of the northward inclination of the land as compared with the modern stand, the shore of the first stage of Ancyclus Lake falls from 115 m. at Degerfors to 0 at Kalmar and to -40 m. south of Bornholm. The southwestern Baltic and the Danish Seas formed land.

As the outlets at Degerfors were upheaved the lake-level was raised until it ultimately reached 32 to 33 m. above the then sea, and the lake transgressed south of the outlets where the uplift was less rapid. Finally the water had risen to the threshold in the southwestern Baltic, to the Darsser Schwelle now 18 m. deep, and Ancyclus Lake began to discharge through the Great Belt. Because of continued uplift of the Degerfors region and sinking of the south Baltic region, the new outlet soon took the whole discharge, and the Degerfors outlets ran dry after having been in use for probably 600 to 700 years.

Ancyclus Lake, which gradually changed into the Littorina Sea, may have existed from about 9500 to 7500 years ago.

ERNST ANTEVS.

Boggy ground in southern Sweden (English and Swedish); by LENNART VON POST. Sveriges Geol. Undersökning, Ser. Ba, No. 11. Map in 1:500,000. Stockholm, 1923; explanation, 1927.—This map, compiled from the geological sheets in connection with the detailed investigation of the peat resources which is being carried out by the Swedish Geological Survey, gives an excellent general view of the regional and topographical distribution of the boggy ground in southern Sweden.

ERNST ANTEVS.

The Geology of the Country near Hastings and Dungeness; by H. J. OSBORNE WHITE. Pp. xii, 104; pls., figs., and two large colored maps issued separately. (Memoirs of the Geological Survey of England; Explanation of Sheets 320 and 321.) London, 1928 (H. M. Stationery Office, 3 shillings).—This memoir forms one of a series of areal reports covering a new edition of the 1 inch to 1 mile sectional geologic maps of England. The area dealt with lies on the coast of Sussex and Kent and includes a portion of the South Downs. The beds exposed are therefore the Purbeck and Lower Wealden, partly covered by alluvium, beach deposits, and eolian sand. The stratigraphy, paleontology, and structure are discussed in detail. This discussion is followed by a résumé of the growth of the Dungeness foreland. A chapter on water supply, soils, and building materials completes the report.

R. F. F.

Die Diamantenwüste Südwest Afrikas. Zugleich Erläuterung zu einer geologischen Spezialkarte der südlichen Diamantfelder; by ERICH KAISER, with additional papers by nine others. Vol. I. Pp. x, 321 with 13 geologic maps, most colored, in pocket. Vol. II. Pp. vii, 535 with 48 engraved plates, and numerous stereoscopic views in pocket. Size $9\frac{1}{2} \times 12\frac{1}{2}$ inches. Berlin, 1926 (Ernst Vohsen. RM 120).—Complete organization and thorough detail mark the contents of this work, which is set off to still greater advantage by the fact that it represents an unusually fine example of the art of the printer and bookbinder.

The completed work is the outcome of a detailed topographic survey begun in 1908, followed later by a sojourn of nearly five years in the field on the part of the author. While the ultimate purpose of the work was to furnish additional data concerning the origin and occurrence of the diamonds for which the region is noted, the bulk of the discussion is concerned with the general geology of the region, under the several headings of physiography, stratigraphy, petrography, structure, paleontology, and geologic history. The physiographic discussion deals largely with processes of erosion and sedimentation in the Namib Desert, and with an extensive series of coastal terraces and raised beaches. The sedimentary rocks are shown to be chiefly Tertiary, overlying Cambrian (?) sediments and schists and gneisses of doubtful age, extensively affected by a complex series of intrusions. Structural features are close N-S folding and the later development of rift valleys. In a series of special papers the invertebrate and vertebrate faunas are discussed and figured. There is even a paper on the anthropology of the native Bushmen!

The diamonds are described as occurring in piedmont fluvial deposits in the arid coastal zone. They are thought to have been freed by the weathering of parent igneous rocks, spread out in fanglomerates, and later (in the early Tertiary) concentrated in part by reworking and deposition along well-defined drainage lines.

The work is illustrated in several ways. Explanatory sketches and diagrams are scattered through the text. In Volume II there are 48 engraved plates with more than 100 separate illustrations, including several splendid oblique views from the air. Most of the pictures are physiographic, but plates of fossils and micro-petrographic photographs are included as well. In a pocket are a number of excellent stereoscopic views of various desert features. Volume I contains a detailed geologic map, on a scale of 1:25,000, in six sheets with an additional sheet of structure sections. Several other more specialized maps are included. Discussion of the illustrations would not be complete without mention of two beautifully colored frontispiece plates reproduced from pastels of desert ranges. An extensive bibliography and a really service-

able index add the finishing touches to this remarkably complete and well-planned book.

R. F. F.

The Geology of the Tongaporutu Subdivision, Taranaki Division; by L. I. GRANGE. New Zealand Department of Scientific and Industrial Research, Geological Survey Branch (P. G. MORGAN, Director). Bulletin 31 (New Series). Pp. vi, 63; plates, map in pocket. Wellington, 1927 (12 shillings).—Bulletin 31 is a member of the series of systematic areal reports which have been appearing regularly during the last few years. New Zealand has been divided into large land-districts which in turn are made up of rectangular subdivisions. Eight subdivisions, together embracing 1021 square miles on the western side of the North Island, are here discussed. The underlying rocks, chiefly faulted Tertiaries, are plotted in detail on colored subdivisional maps on a scale of 1:63360.

R. F. F.

Iowa Geological Survey, Volume XXXII. Annual Reports, 1925 and 1926, with accompanying papers. (GEORGE F. KAY, State Geologist.) Pp. 557; figs., plates, and maps. Des Moines, 1927 (Published by the State).—The following papers are included in this collection: Mineral Production in Iowa in 1925 and 1926, by James H. Lees; Rock Resources of Iowa, by George F. Kay; Iowa Coal Areas and Characteristics of Iowa Coal, by James H. Lees; The Use of Iowa Coal for Steam Production, by T. A. Marsh; Possible Researches in Iowa Coal, by B. P. Fleming; Geology of Lucas County, by Alvin L. Lugin; Geology of Crawford County, by James H. Lees; Altitudes in Iowa, by James H. Lees. The county reports include large colored geologic maps.

R. F. F.

The Fusulinidae of the Pennsylvanian System in Nebraska; by CARL O. DUNBAR and G. E. CONDRA. Nebraska Geol. Surv., Bull. II, Second Series, pp. 1-135, pls. I-XV, text figs. 1-13, 1927.—This work is the result of the study of collections made from every fossiliferous outcrop in the state of Nebraska as well as from adjacent areas. While the work is primarily a description of the species of Nebraska, its value to many workers and teachers dealing with the Foraminifera is in its other chapters. The chapter on the "Morphology of the Fusulinid Shell" is a masterpiece of clear English dealing with details of structure where there has been much confusion. The diagrammatic figures make clear the structure of these complex tests and a much greater clarity and uniformity in terminology dealing with the morphology of this group should result. The "Glossary of Anatomical Terms" with the correlated table showing the equivalent terms used by various authors is a much needed feature which will be warmly welcomed by all workers dealing with the group. An excellent review of the classification of the family is given, with a review of the different genera in accordance with the geno-

types and the Rules of Nomenclature. The groupings of earlier authors are given, and finally as a result of this review an amended classification of the family is offered with descriptions of the genera, geological ranges and synonyms.

The various species are very fully described and illustrated by a series of excellent photographs of exteriors and sections in different planes. The discussion under each species is full and helps much in the understanding of the species, their differences from related species, and their detailed structure.

An annotated bibliography will also be found useful for those whose interest in the group is awakened by this interesting paper.

Altogether, for its excellent attention to detail, both in the morphology of the group in general and in specific description, this work should be held up as an excellent standard to be emulated by other workers attempting to study a whole family of the Foraminifera.

JOS. A. CUSHMAN.

United States Bureau of Mines; SCOTT TURNER, Director. Recent publications of the Bureau of Mines are given in the following list. (See earlier, vol. 14, 166, 502.)

Bulletins. No. 229. Fifty-nine coal mine fires; by G. S. RICE, J. W. PAUL, and M. W. VON BERNEWITZ. Pp. 156; 61 figs. (40 cents).

No. 245. Mining of thin coal beds in the Anthracite Region of Pennsylvania; by D. C. ASHMEAD. Pp. 113; 57 figs. (30 cents).

No. 274. Potash mining in Germany and France; by G. S. RICE and J. A. DAVIS. Pp. 92; 23 figs. (25 cents).

No. 277. Safety in coal mining; by G. S. RICE. Pp. 141; 1 fig. (25 cents).

No. 279. Limits of inflammability of gases and vapors; by H. F. COWARD and G. W. JONES. Pp. 99; 21 figs. (20 cents).

No. 283. Coal-mine fatalities in the United States: 1926; by W. W. ADAMS. Pp. 121 (15 cents).

No. 287. Gases from blasting in tunnels and metal-mine drifts; by E. D. GARDNER, S. P. HOWELL, and G. W. JONES. Pp. 96; 14 figs. (20 cents).

No. 289. Petroleum refinery statistics; by G. R. HOPKINS. Pp. 92; 4 figs. (20 cents).

No. 291. Tabulated analyses of representative crude petroleum of the United States; by N. A. C. SMITH and E. C. LANE. Pp. 69 (20 cents).

Also Technical Papers, Nos. 411, 414, 416, 418, 421, 427, 429, 433. Prices from 5 to 20 cents.

Orders and remittances for copies of publications should be sent directly to The Superintendent of Documents, Government Printing Office, Washington, D. C. (not to the Bureau of Mines).

West Virginia Geological Survey; DAVID B. REGER, acting

State Geologist. The following addition to the important series of the Geological Reports of the Counties in West Virginia, which have now covered the larger part of the State, has recently been issued.

Detailed Report on Hampshire and Hardy Counties. Pp. xxiv, 624; 77 pls., 19 text figs.; also separate case of topographic and geologic maps of both counties. Price \$3.00. (This report can be obtained from the W. Va. Survey. P. O. Box 848, Morgantown, W. Va.)

The report on Hampshire County is by JOHN L. TILTON assisted by PAUL H. PRICE. Hardy County is described by WM. F. PROUTY, assisted by R. C. TUCKER and PAUL H. PRICE. The two counties named lie in the extreme northeast part of the State. They contain no commercial deposits of coal but large deposits of limestone and low grade iron ores.

United States Geological Survey; GEORGE OTIS SMITH, Director. Recent publications of the U. S. Geological Survey are noted in the following list. (See earlier vol. 14, p. 165.)

TOPOGRAPHIC ATLAS. Forty-four sheets.

PROFESSIONAL PAPERS—No. 150, C, D, E, F. Shorter Contributions to Geology. Pp. 41-140.

No. 152. Geography, geology, and mineral resources of part of southeastern Idaho, by G. R. MANSFIELD, with descriptions of Carboniferous and Triassic fossils, by G. H. Girty. Pp. xiii, 453; 70 pls. (incl. 19 maps), 46 figs. This volume is noticed elsewhere. Price \$2.40. (Copies may be obtained from The Superintendent of Documents, Government Printing Office, Washington, D. C.)

FORTY-EIGHTH ANNUAL REPORT of the Director for the fiscal year ended June 30, 1927. Pp. ii, 77. A detailed account of the work of the Geological Survey during the year. The work was done in all parts of the country, largely in coöperation with the States.

BULLETINS.—Nos. 795, 796. Contributions to Economic Geology. 795, Part I. G, H. Pp. 147-221. 796, Part II. B, C, D. Pp. 65-197.

No. 788. Topographic Instructions. E. Mapping; by W. M. BEAMAN. Map compilation from aerial photographs; by T. P. PENDLETON.

WATER SUPPLY PAPERS. Nos. 577, 579, 596. G. and H.

Museum of the City of Milwaukee. The following Bulletins have been recently issued:

Ethnobotany of the Meskwaki Indians; by HURON H. SMITH. Vol. 4, No. 2. Pp. 175-326; pls. 37-46.

Amphibians and Reptiles of Wisconsin; by T. E. B. POPE and W. E. DICKINSON. Vol. 8, No. 1, pp. 1-138; pls. 1-21, text figs. 1-28.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Das Pflanzenreich; by A. ENGLER. Heft 90, (IV, 228), by HERMANN WOLFF. Umbelliferae-Apioideae-Ammineae-Carinceae, Ammineae novemjugatae et genuineae. Leipzig, 1927 (Wilhelm Engelmann).—This volume of the series of taxonomic monographs edited by A. Engler was prepared by Hermann Wolff, and deals with one group of the *Umbelliferae*, the sub-tribe *Carinceae* of the tribe *Ammineae* and the sub-family *Apiodeae*. In the work, which comprises 398 pages with 152 illustrations grouped in 26 figures, 60 genera are considered, the largest being *Apium* with 31 species, *Cicuta* with 20, *Carum* with 20, *Bunium* with 28 and *Pimpinella* with 141. Six new genera, (*Sonderina*, *Meringogyne*, *Baumiella*, *Hellenocarum*, *Schimperella*, and *Adenosciadium*) are created, and four new species (*Pimpinella Thellungiana*, *P. Friesiorum*, *Acronema Handelii*, *Carum Breitschneideri*) described. Many new names and combinations are established. The volume follows the same method of treatment as the earlier numbers of the series and keeps to the same high standards of excellence.

A. F. HILL.

No. 89 (IV, 105) of the above work, on "Das Pflanzenreich," by A. ENGLER, has been prepared by O. E. SCHULZ and embraces the *Cruciferae-Draba* and *Erophila*. It is fully illustrated with 428 single pictures in 35 figures.

A Course in General Biology; by HENRY SHERRING PRATT. Pp. xiii, 178. Boston, 1928 (Ginn & Co., \$1.48).—This manual is intended to supplement text-books and lectures in laboratory courses in general biology. It is so arranged that teachers may select exercises in any order they please. Probably few classes would find time to dissect all the organisms as completely as treated in this book. Following a short introduction, the frog is chosen as the representative of the Phylum Chordata. Eleven arthropods, two annelids (*Lumbricus* and *Nereis*), one turbellarian (*Planaria*), three molluscs (clam, oyster, land snail), one echinoderm (*Asterias*), three coelenterates (*Hydra*, *Pennaria*, *Gonionemus*), a sponge (*Grantia*), and five protozoa (*Paramecium*, *Vorticella*, *Euglena*, *Amoeba* and *Arcella* or *Diffugia*) are presented in order. For a study of the cell, mounted sections of the onion root tip are required.

The plant kingdom is studied in the reverse order. Pleurococcus, a desmid, a diatom, and spirogyra among the algae are considered. Yeast, bacteria, black and blue-green molds, all of which can easily be observed alive, represent the fungi. For the Phylum Pteridophyta directions are given for a study of the common fern (*Pteris aquilina*). The stem (twig of a tree), the leaf (entire, and in section), the root (carrot), the flower, fruit and seed (bean pod) are provided for in the consideration of the

Phylum Spermatophyta. In the appendix is an outline classification of the animal and plant kingdoms. A convenient glossary and index of organisms treated is added. S. C. B.

Natural History of Animals: An Illustrated Who's Who of the Animal World; by GEORGE JENNISON. Pp. xv, 344; 309 figs., 15 pls. and frontispiece in color. London and New York, 1927 (The Macmillan Company, \$4.50).—Out of his long experience as Curator of the Bellevue Zoological Gardens at Manchester, England, the author has written an attractive and concise reference book in which representative mammals are arranged according to the natural classification from Primates to marsupials. For examples of each important genus and of many species the habitat, size, general shape, and color, length of life, number of young and food is given. Each species is illustrated by a photograph from life. To this information have been added many notes on habits of the animals in their native haunts and in captivity. This volume is distinctly a new departure in natural histories. S. C. B.

Childbirth; by WILLIAM G. LEE. Pp. xi, 300; 22 figs. and frontispiece; Chicago, 1928 (Univ. of Chicago Press, \$3.00).—This is an attractive volume by Dr. Lee, who up to the time of his death was on the faculty of Rush Medical College and Chief of the Obstetrical Staff of the Cook County Hospital, Chicago.

In the first chapters the author discusses the pelvis, the physiology and management of labor, the conditions which demand operative interference, and the nature and objects of such operative procedures. Of the following chapters, one deals with the management of labor when complicated by the presence of a contracted pelvis, and with the treatment of atypical feto-maternal relations. Two are devoted to a discussion of the importance and technique of the forceps operation, and throughout these pages the author emphasizes the value of the Kjellands instrument. The final chapter deals with the administration of hospitals, and contains suggestions which, if adopted, would lead to more efficient work on the part of the obstetrical staff and to a greater benefit to the community.

In going over the pages, one receives the impression that Dr. Lee was a high-minded gentleman, and a conservative and conscientious obstetrician. Although opinions may differ on certain points of technique, one must, as Dr. Hilles has pointed out in his prefatory note, "respect the opinions that developed in a trained mind after years of careful observation in the labor room and hospital."

The grammatical construction of the text is excellent, and the volume is recommended to medical students and to others who are interested in obstetrics.

ARTHUR H. MORSE.

OBITUARY.

PROFESSOR HIDEYO NOGUCHI, bacteriologist of the Rockefeller Institute of Medicine, died of yellow fever at the age of fifty-two years. His death occurred on May 21, at Accra, Gold Coast Colony, Africa. The disease was contracted during a laboratory experiment, but with the devotion to science that characterized his life, he continued his studies during his illness. The result of his personal sacrifice has been the solution of the problem he went out to study. He succeeded in proving the relationship between the yellow fever of South America and of Africa and the source of the latter.

DR. S. NAZAWA, professor in the University of Hokkaido and a well-known ichthyologist, died on March 23.

PROFESSOR V. L. OMELIANSKI, the Russian bacteriologist and a member of the Russian Academy of Sciences, died on April 21.

DR. JOHN HORNE, assistant director of the Geological Survey of Scotland from 1901-1911, died on May 30 at the age of eighty years.

DR. C. G. JOHANNES PETERSEN, director of the Danish Biological Station, has died recently.

SIR DAVID FERRIER, the veteran British neurologist, died on March 19, at the age of eighty-six years.

DR. BERNHARD WANACH, professor of astronomy at the Geodetic Institute in Potsdam, Germany, died recently.

DR. THEODORE ZINCKE, professor of chemistry in the University of Marburg, has died.

DR. WILHELM VON BRANCA, formerly professor of geology and paleontology at the University of Berlin, died on March 12 at the age of eighty-three years.

DR. JULIUS HIRSCHWALD, professor of mineralogy at the Berlin Technische Hochschule from 1877 to 1921, has died at the age of eighty-three years.

DR. CHARLES H. GILBERT, professor of zoology at Stanford University, died on April 20 at the age of sixty-eight years.

DR. JOSEPH NELSON ROSE, associate curator of botany in the U. S. National Museum, died on May 4, at the age of sixty-six years.

DR. JOHN SMITH DEXTER, professor of zoology in the University of Porto Rico, died on April 19 at the age of forty-two years.

DR. CHASE PALMER, of the U. S. Geological Survey, died recently at his home in San Francisco at the age of fifty-nine years. He was widely known for his researches in the chemistry of ores, minerals, and waters. He was particularly interested in the waters naturally associated with oils and developed a system of classification to bring out those features which is now in general use among geologists.

EDGAR FAHS SMITH.

1856—1928.

The death of Dr. Edgar Fahs Smith on May 3d deprived American Science of one of its most devoted followers and American scientists of one of their most charming and beloved personalities.

Dr. Smith was born in York, Pennsylvania, on May 23, 1856. His interest in chemistry developed very early while he was a student at Pennsylvania College, Gettysburg, from which institution he graduated in 1874. In this year, he began his advanced training under Wöhler at the University of Göttingen, and received his Doctorate from that institution in 1876. Upon his return from Germany, he became an assistant in analytical chemistry at the University of Pennsylvania under Professor Genth. In 1881, he accepted the Asa Packer Professorship of Chemistry at Muhlenberg College, which he held for two years, and in 1883 he went to Wittenburg College. In 1888 he returned to the University of Pennsylvania as professor of analytical chemistry and in 1892 became Director of the Chemistry Department, which position he held until his retirement in 1921. From 1898 to 1911 he was Vice-Provost, and from 1911 to 1921, Provost of the University of Pennsylvania.

Dr. Smith's career as an investigator was marked by many contributions and many notable successes. His excellent series of contributions to electro-chemical analysis were begun in 1879 and continued for many years. His studies in the field of inorganic chemistry included the introduction of new analytical methods, the determinations of the atomic weights of some twenty elements, investigations of complex inorganic compounds, and, particularly, the inorganic chemistry of columbium, tantalum, molybdenum, and tungsten. In more recent years, many interestingly and attractively written books and pamphlets relating to the History of Chemistry in America were penned by Dr. Smith. His life as a scientist and as a provost brought to him honors from all parts of the world. He was a member of many societies and was president of the American Chemical Society three times.

Surely his life was characterized by an indefatigable zeal. During a few years while attending to the arduous duties of vice-provost of the University of Pennsylvania, he lectured and taught twelve to fifteen hours a week, directed the research of a large laboratory, and found time to translate the two volumes of Richter's Organic Chemistry as well as one volume of Richter's Inorganic Chemistry. But just as surely his life was characterized by a delightful kindness which one could never forget who had had the pleasure of knowing him or who had visited him in his unique library where the old prints, the old *Chemistries*, and the historical scientific documents took on a living significance through the memory and spirit of the man.

HERBERT S. HARNED.



MINERVA

Jahrbuch der gelehrten Welt

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Neunundzwanzigster Jahrgang 1928

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AUGUST 1928

THE DENSITY OF THE ISLAND OF HAWAII, AND DENSITY DISTRIBUTION IN THE EARTH'S CRUST.

ROY W. GORANSON.

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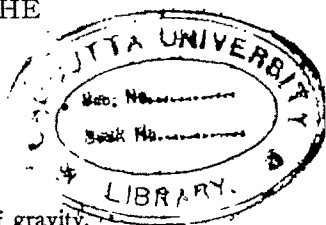
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INTRODUCTION.

The writer's attention was first attracted to this subject in attempting to calculate the density of the rock mass composing the Hawaiian Islands. In order to bring the measured rock densities into agreement with those deduced from gravitational data it was found necessary to make a more extended study of these relationships.

This study included an investigation of the relative values of gravity in continents and at sea in relation to various hypotheses of isostasy and of density distribution in continental masses.

From this study an hypothesis was adopted which satisfied the physical and geological data collected and led to density values for Hawaii which were in satisfactory agreement with the observed values.



The writer desires here to express to the U. S. Coast and Geodetic Survey his appreciation of their kindness in supplying him with gravity measurements.

I. GENERAL STATEMENT.

The prevailing theory of isostasy has been accepted generally by geologists and geophysicists. The agreement on how and in what precise concrete form the theory should be expressed is, however, not so good. In the present discussion we shall not be concerned with the mechanism by which isostasy operates but shall attempt to bring together some of the essential data in order to focus attention on certain points important to the mathematical formulation of the theory.



The general procedure in acquiring gravity data is to measure the attraction of the earth on a certain mass at various points on the earth's surface. This attraction is expressed as a force, F , in dynes acting on a unit mass, $F = k \frac{m}{r^2}$, or as an acceleration, a , in cm/sec^2 , $a = \frac{F}{M}$.

The value obtained, called the observed value, is then compared with a theoretical value of the gravitative force computed for the point. The calculation of the theoretical value is based on empirical data and assumptions some of which we shall discuss in the following pages.

Where the observed value of the attraction exceeds the theoretical or calculated value we say there is a positive difference or positive gravity anomaly at this point.

II. DETAILS IN THE CALCULATION OF THE THEORETICAL VALUE OF GRAVITY.

It will be desirable at this point to summarize briefly the procedure for calculating gravity anomalies.

Some of the data necessary for the calculation of the theoretical value of gravity are

- (1) Shape of the earth as a whole, which we shall call the geoidal shape.
- (2) Correction due to deviation from this geoidal shape, i.e. to surface irregularities.
 - (a) Correction for position of station with reference to geoidal surface, and called correction for elevation.
 - (b) Correction for the attraction of excess material above the geoidal surface or of a deficiency of material represented by hollows lying below the geoidal surface, and called correction for topography.
- (3) Correction for isostatic compensation. This is to correct for the deficiency or excess of mass below the surface of the earth and is found to be related directly to the rock mass above the geoidal surface.

(1) *Shape of the earth.*

The figure that has been used by the U. S. Coast and Geodetic Survey is that of an ellipsoid with an ellipticity¹ of $1/297.4 \pm 1.0$. This is Helmert's formula revised by Bowie² on the basis of gravity data from 358 stations, most of which

¹ Helmert (Sitz. d. K. Pr. Akad. d. Wiss. 41, p. 676, 1915) obtained from 410 gravity stations an ellipticity of $1/296.7 \pm 0.4$. He did not correct the gravity values for topography nor for isostatic compensation. He has also computed a formula treating the earth as a triaxial ellipsoid.

² Bowie, William, U. S. Coast and Geod. Surv., Sp. Pubn. 40, 134, 1917.

were in the United States. According to this formula gravity varies with latitude.

Heiskanen³ has reanalyzed the data, adding much new material from Europe, Africa, and Asia, 640 stations in all. He treated each continent separately and found that Europe and Africa gave an appreciably larger mean value of gravity and a larger ellipticity than America or Asia. He thus finds that the geoid is more nearly a triaxial ellipsoid; the maximum value of the ellipticity, $1/299 \pm 0.6$, is in 18° E., the minimum value, $1/294.3 \pm 0.6$, is in 72° W. of Greenwich. The mean value of the ellipticity is $1/296.7 \pm 0.5$. According to this formula gravity varies with both latitude and longitude.

Accepting Heiskanen's result as the most probable general expression of those proposed for the ellipticity, we shall begin with the assumption that the expression for gravitative attraction can be represented in the following form:

$$g_0 = [g\{1 + A_1 \sin^2\phi - A_2 \sin^2 2\phi + A_3 \cos^2\phi \cos 2(\lambda - 18)\} + H] + T + C$$

where

g_0	denotes the gravity value at the point under discussion,
g	the gravity at sea level at the equator and 18° E.
	longitude,
A_1, A_2, A_3	constants,
ϕ	the latitude of the point under discussion,
λ	the longitude of the point,
H	the correction for elevation for the point above sea level,
T	the correction for topography above sea level,
C	the correction for excess or deficiency of mass below sea level referred to the column that is accepted as standard; this term has been called the correction for isostatic compensation.

The expression in {} brackets multiplied by g has been called γ_0 , and that in square brackets the free air reduction.

If we accept the constants which have been determined from the geodetic data by Heiskanen, we have

$$\begin{aligned} g &= 978.052 \text{ dynes} \\ A_1 &= 0.005 \ 285 \\ A_2 &= 0.000 \ 007 \\ A_3 &= 0.000 \ 027 \end{aligned}$$

³ Heiskanen, W., *Untersuchungen über Schwerkraft und Isostasie*, 80-96, 1924.

$$g_t = 2\pi\rho k \left[\int_0^r \left\{ \frac{r}{\sqrt{r^2 + (L_1 - l_1)^2}} - \frac{r}{\sqrt{r^2 + L_1^2}} \right\} dr + \dots \dots \dots \right. \\ \left. + \int_{r_{n-1}}^{r_n=R} \left\{ \frac{r}{\sqrt{r^2 + (L_n - l_n)^2}} - \frac{r}{\sqrt{r^2 + L_n^2}} \right\} dr \right]$$

which is the general form of the graphical solution which the Coast and Geodetic Survey use in calculating the effect of topography. They take $n=33$, the zones being of variable widths in order to equalize the error involved in each approximation.⁶ Their listed tables⁶ are calculated for a uniform density of 2.67.

Some other formulae which have been found useful are:

- (a) Attraction of a cylindrical mass on a station situated on its axis or axis produced. This equation has just been derived but is set down again here in its simpler form.

Let the topographic features be expressed as a cylinder with the station lying on its axis or axis produced and assume the density to be constant. Let r denote the radius of the cylinder, h the height of the station above the cylinder, and l the length of the cylinder. Then

$$g_t = \rho k \int_0^{2\pi} d\phi \int_h^{h+l} dz \int_0^r \frac{sr dr}{(r^2 + z^2)^{\frac{3}{2}}} \\ = 2\pi\rho k [l + \sqrt{r^2 + h^2} - \sqrt{r^2 + (h+l)^2}] \text{ where } h \geq 0 \\ = 2\pi\rho k [l + 2h - \sqrt{r^2 + h^2} + \sqrt{r^2 + (h+l)^2}] \text{ where } h < 0, h+l > 0$$

- (b) Attraction of a conical mass on a station situated at its vertex.

Let the topographic features be represented as a cone with the station at its vertex and assume the density to be constant. Let l denote the height of the cone and r the radius of the base. Then

$$g_t = \rho k \int_0^{2\pi} d\phi \int_0^l dz \int_0^{\frac{sr}{l}} \left\{ \frac{z}{(r^2 + z^2)^{\frac{3}{2}}} \right\} r dr \\ = 2\pi\rho k \left[l - \frac{l^2}{\sqrt{r^2 + l^2}} \right]$$

⁶ Hayford, J. F. and Bowie, William, U. S. Coast and Geod. Surv., Sp. Pubn. No. 12, 18, 1912.

⁶ idem, pp. 30-58.

This equation can be identified with the Bouguer formula or Young's rule as it has been called if we replace k by $\frac{3g}{4\pi R\Delta}$, where g denotes the force of gravity at sea level, Δ the mean density of the earth, and R the radius of the earth.

(c) Attraction of a spherical segment on a station situated at or above the mid point of its surface.

Let the topographic features be expressed as a spherical segment with the station lying on the mid point of the surface of the segment or on the radius which joins this point produced. We shall call this radius the vertical radius. Let r be the radius of the spherical segment, l be the height of the segment measured along the vertical radius, and h the elevation of the station above the surface of the segment measured along the vertical radius produced. Then

$$g_t = \rho k \int_0^{2\pi} d\phi \int_h^l dz \int_0^{\sqrt{r^2 - (r+h-z)^2}} \frac{zr}{(z^2 + r^2)^{\frac{3}{2}}} dr$$

$$= 2\pi\rho k \left[l - \frac{h(3r+2h) + l(r+h)}{3(r+h)^2} \sqrt{h^2 + 2l(r+h)} + \frac{h^2(3r+2h)}{3(r+h)^2} \right] \text{ where } h > 0, l < r$$

$$= 2\pi\rho k \left[l - \frac{\sqrt{2l^3}}{3r^{\frac{1}{2}}} \right] \text{ where } h=0, l < r$$

$$= 1.057 \pi\rho k \text{ where } h=0, l=r$$

Thus if we consider a spherical shell of thickness t , outer radius r (inner radius $= r-t$), and height l measured along the vertical radius, and the station on the mid point of the outer surface, we have

$$g_t = 2\pi\rho k \left[l - \frac{\sqrt{2l^3}}{\sqrt{r}} - (l-t) + \frac{t(2r+t) + l(r+t)}{3(r+t)^2} \sqrt{2l(r+t) - t(2r+t)} - \frac{t^2(3r+2t)}{3(r+t)^2} \right]$$

where $t > 0, t < l < r$.

If $l=r$ this expression reduces to

$$g_t = 2\pi\rho k \left[t - \frac{2r}{3\sqrt{2}} + \frac{(r+t)^2 + rt}{3(r+t)^2} \sqrt{2r^2 - t} - \frac{t^2(3r+2t)}{3(r+t)^2} \right]$$

* $l = 2R \sin^2 \frac{1}{4} \phi$, where ϕ is the angle subtended at the center.

3. *Correction for Isostatic Compensation.*

According to the general theory of isostasy all or part of the difference between the observed value and the calculated value, corrected by the foregoing methods, should represent the correction which corresponds to the effect of isostatic compensation on the value of gravity.

The corrections applied for isostatic compensation are the weak links in this developed theory, since there is no direct check on any proposed method other than that it should make the theoretical values correspond with the observed value of the gravitational attraction.

Two density distributions have been proposed to account for the variations of gravitational attraction after the corrections given in the previous part of this paper have been applied. One of these was suggested by J. H. Pratt⁸ and the other by G. B. Airy.⁹

Pratt's hypothesis assumes that topographic features are due to variations in the expansion of vertical rock columns which are supposed to extend down to a certain uniform depth; the expansion is assumed to be such that the rock has the same density at all points of the same column but differs for each column. Since the rock is assumed to have been initially of the same kind under each point, each column must have the same mass.

This is the hypothesis which the U. S. Coast and Geodetic Survey have accepted in calculating the correction for compensation. They take as reference a "sea coast column," which is a column of rock extending from sea level to the depth at which isostatic compensation is practically complete. Let this depth be denoted by h_1 . Hayford and Bowie assume it to have a uniform density, δ , of 2.67. Then according to this hypothesis the rock in an ocean column down to a depth $h_1 - D$ below the ocean floor will have a uniform density of

$$\delta + \frac{(\delta - 1.027)D}{h_1 - D}$$

where D is the depth of the ocean; similarly the rock below sea level in a continental column down to a depth h_1 will have a uniform density of

$$\delta - \delta \frac{H}{h_1}$$

where H is the elevation above sea level.

⁸ Phil. Trans. Roy. Soc. London, vol. 145, 53-100, 1855.

⁹ Phil. Trans. Roy. Soc. London, vol. 145, 101-104, 1855.

Different values for the depth of compensation, h_1 , after the Pratt hypothesis, have been proposed in the publications of the U. S. Coast and Geodetic Survey. Some of these are:

	Depth of Compensation
Hayford, J. F. and Bowie, William, U. S. Coast and Geod. Survey., Sp. Pubn. No. 10, 1912, p. 10	113.7 km.
Hayford, J. F., Supplementary investigations in 1909 of the figure of the earth and isostasy, 1910: Deflection of plumb line at U. S. A. stations	122.2 km.
Bowie, William, U. S. Coast and Geod. Survey., Sp. Pubn. No. 40, 1917, p. 133: From mountain stations in U. S. A.	95 km.
" 216 sta. in U. S. A.	50-60 km.

Airy's hypothesis assumes that a relatively thin outer crust is supported on a denser substratum; that extra loading on the surface will push the crust down, displacing a denser substratum, until the load is balanced almost wholly by the upward pressure on the base of the crust.

III. LIMITING RESTRICTIONS ON METHODS FOR COMPUTING ISOSTATIC COMPENSATION.

From this discussion it can be seen that the uncertainty in the calculation of the theoretical value of gravity lies in the correction to be applied for isostatic compensation.

It will be desirable, therefore, to summarize data which define these limiting conditions which any method for computing such corrections must fulfil.

In order to discriminate between existing expressions for computing the effect of isostatic compensation on gravity values and to formulate other reasonable ones, we need data on

- (1) Lateral and vertical density distribution in the crust.
- (2) Depth of compensation.
- (3) Strength of the crust under surface loads.

1. *Density distribution.*

Some of the arguments which have been used in determining or in setting limits to determinations of the physical character of the crustal rocks and which we shall consider are:

- (a) Geological evidence.
- (b) Heat conduction and the radioactive properties of rocks.
- (c) Seismologic evidence in conjunction with laboratory determination of the physical character of rocks.

a. Geological Evidence. Direct geological evidence gives us the vertical density distribution to a depth of a very few kilometers only. However, from a study of geosynclinal sections, we can reconstruct the crust to many kilometers of depth and obtain an idea of what kind of rock we may expect. For example, we know that in the eastern geosyncline of the western Cordillera of North America 24 kilometers of sediments were deposited from the time of the Beltian (late Pre-Cambrian) to the Upper Cretaceous. These sediments were deposited on a Pre-Cambrian granite and gneiss floor which, from observations of sections in other places, must have been many kilometers thick. Thus at the end of the Cretaceous we had sediments, including sandstones and shales, at a depth of 25 or more kilometers below the Cretaceous sea level. We therefore know that rocks such as we find at the surface of our continents have been projected down to depths of 25 or more kilometers.

In order to obtain an estimate of the density of the surface continental rocks we can use the gravitative attraction between two nearby stations which are at different elevations.

The difference in gravitative attraction between the summit of Pike's Peak (4,293 meters elevation) and Colorado Springs (1,841 meters elevation), after correcting for the difference in latitude and elevation, is 0.221 dynes. This figure represents the attractive force on the station at Pike's Peak of the rock, which is granite, lying between the elevations of Pike's Peak and Colorado Springs. The density of the rock mass necessary to account for this amount of attraction will be 2.7. H. S. Washington¹⁰ gives 2.73 as the average density of the surface rocks of the United States which represents a statistical average of the measured densities of rock specimens.

With respect to lateral distribution, although we have in many cases detailed petrographical information and thus the surface densities of large continental areas, we find that these data cannot be extrapolated to any great depth. Bowie¹¹ has grouped Hayford gravity anomalies with reference to surface geology at the gravity stations. He finds that the anomalies of stations on outcropping Pre-Cambrian rock are predominantly positive while those of stations on outcropping Cenozoic rock are predominantly negative. The anomalies of stations

¹⁰ Bull. Geol. Soc. Amer., 33, 392, 1922.

¹¹ Bowie, William, U. S. Coast and Geodetic Survey, Sp. Pubn. 40, 70-84, 1917.

on Palaeozoic and Mesozoic rock are rather evenly divided between positive and negative. We should expect some such result in Pre-Cambrian rock since the densities of Pre-Cambrian gneisses and schists are from 5 to 10 per cent greater than the corresponding densities of Palaeozoic and Mesozoic sandstones and shales. Similarly the Cenozoic sediments have more porosity than the corresponding Palaeozoic and Mesozoic sediments and will thus be still less dense.

The compensation of an excess or deficiency in mass for isostatic equilibrium occurs at some considerable depth. According to the Pratt-Hayford hypothesis the center of gravity of the compensating column is at 30 km., assuming the depth of compensation to be 60 km. Thus since the attraction varies inversely as the square of the distance the resultant effect of a high density at the surface will be to give an apparent positive anomaly.

b. Heat conduction and the radioactive properties of rocks. We know that the surface rock of our continents is essentially salic or "granitic" in character and that this kind of rock extends to some depth lying beyond our means of direct observation. We are thus compelled to resort to indirect methods if we wish to reconstruct the petrologic relations at greater depths.

Our geological and physical data make it reasonably certain that the density must increase with depth so that at some distance down we should have a density corresponding to that of a basalt. We have not been able, however, to establish with certainty the depth at which the lighter "granitic" rock gives way to more ferric rock.

One of the methods of obtaining an estimate of the thickness of the "granitic" layer is through our theory of heat conduction and the properties of radioactive matter. Much has been written on this phase of the subject but owing to the elasticity of the data presented a great deal of the literature is rather confusing. From the temperature gradient at the surface and data on the conductivity of rocks we obtain the amount of heat given off from the earth. We have the temperature gradient due to the cooling of the earth plus exothermic reactions in the interior to supply this heat. The decomposition of radium and thorium, present in rocks, will provide some of the heat. We also know that potassium, a constituent of crustal rocks, decomposes in an exothermic reaction which should also be included in our calculation.

TABLE I.

Rock	gm Ra $\times 10^{-13}$ /gm rock ^a	gm Th $\times 10^{-6}$ /gm rock ^a	gm K $\times 10^{-3}$ /gm rock ^b	density ^c
Granite	(176) 2.732	(144) 15.05	(581) 3.42	(308) 2.66
Syenite, monzonite	(71) 4.1		(92) 3.65	(13) 2.76
Diorite	(12) 1.99		(179) 2.08	(66) 2.86
Basalt	(53) 1.185	(78) 8.106 ^d	(376) 1.27	(104) 2.88
Diabase, gabbro, dolerite	(27) 1.3		(108) 0.72	(208) 2.94
Dunite, peridotite, hypersthene	(4) 0.315		(41) 0.63	(59) 3.31
Stony meteorites	(19) 1.08			
Iron meteorites	(2) 0.69			
	(5) 0.00			

(The figures in brackets denote the number of specimens averaged for the given value.)

^a For reference see International Critical Tables, vol. I, 377-8, 1926.^b Daly, R. A., *Igneous Rocks and Their Origin*, 1914.^c Compiled from various sources, some of which are:Daly, R. A., *Igneous Rocks and Their Origin*, 39, 1914.Washington, H. S., *Prof. Paper U. S. G. S.* 99, 1917.Becke, F., *Sitzungsber. k. Akad. Wiss. Naturw. Kl.* 120, 265, 1911.Douglas, I. A., *Quart. Jour. Geol. Soc. London*, 53, 145-161, 1907.Washington, H. S., *This Journal* 5, 465-502, 1923.Washington, H. S., *This Journal* 6, 409-424, 1923.Barus, C., *Bull. U. S. G. S.* 103, 1893.Dav. Sosman, *Hostetter, This Journal* 37, 1-37, 1914.^d Joly, *The Surface History of the Earth*, p. 69, cites for Deccan (6); Hebridean (6) and Columbia River (7) basalt (av. of 19 sp.)8.6 $\times 10^{-4}$ gm Th per gm basalt and 1.16 $\times 10^{-13}$ gm Ra per gm basalt; from 58 basalts 7.7 $\times 10^{-3}$ gm Th/gm basalt, Phil. Mag., No. 1924.

The foregoing table gives what seem to be the best data available on the radium, thorium, and potassium content of more or less representative samples of the various rocks listed.

The energy liberated by Ra, Th, and K used in this calculation is given below in terms of calories per hour per gram of substance.

Radium— $137.7^{13, 18}$ (heat production of 1 gm. radium together with its short-lived products in equilibrium with it)

Thorium $2.37 \times 10^3^{14}$

Potassium $1.415 \times 10^8^{14}$

If we assume an infinite age for the earth we can write the equation for heat conduction in the following form:

$$x_g = \frac{k}{A} \left[\left(\frac{d\theta}{dx} \right)_s - m \right]$$

where x_g denotes the depth of the "granitic" layer,
 k the conductivity of the "granitic" layer,
 A the heat produced in the surface layer due to radioactive energy generated,

$\left(\frac{d\theta}{dx} \right)_s$ the temperature gradient at the surface; and
 m the temperature gradient due to the cooling of the earth.

We shall assume, following L. H. Adams, that

$$\left(\frac{d\theta}{dx} \right)_s = 0.00035^\circ/\text{cm.}, \quad m = 0.00004^\circ/\text{cm.}$$

We shall assume $k = 0.007^{16}$ for salic rocks
 $= 0.0055$ for intermediate rocks
 $= 0.0035^{17}$ for femic rocks.

From these data we obtain for the thickness of the layer which will supply from radioactive sources the heat lost:

¹³ Rutherford and Robinson (Sitz. Akad. d. Wiss. in Wien, Mat.-Natur. Kl. 121, 1491, 1912) found it to be 135 cal/hr. St. Meyer and Hess (ibid, p. 603) found it to be 137 cal/hr. Holmes and Lawson (Nature, 117, 620-1, 1927) believe these two results to be too low owing to the fact that in all probability an underestimate was made of the effect of the γ -rays which were not entirely absorbed in the experiments.

¹⁴ Joly, J., Surface History of the Earth, p. 70, uses 201.6 cal/hr. but cites no reference for it.

¹⁵ Pegram, G. B., and Webb, H. W., Phys. Rev., 27, 25, 1908. They obtained 9.6×10^8 cal/hr/gm of 46 per cent active ThO_2 together with its short-lived products in equilibrium with it.

¹⁶ See Holmes and Lawson, Nature, 117, 620-1, 1927, for references.

¹⁷ Stadler obtained (4 specimens) $k = 0.007981$ and k^2 (diffusivity) = 0.01647 for granite; $k = 0.00685$ for andesite. See Schulz, Karl, Fortschr. Mineral. Krist. Petrog. 9, 378-80, 1924.

¹⁸ Bridgman, P. W., This Journal 7, 89, 1924, obtained for the conductivity of basalt ($\rho = 2.924$ at room temp.),

Rock	Calorific value	$k \left[-\frac{d\theta}{dr} - m \right]$	Thickness of layer
	cal/hr/cm ²	cal/hr/cm ²	km.
granite	3.237×10^9	7.812×10^3	24.1
diorite	2.646×10^9	6.14×10^3	23.2
basalt	1.541×10^9	3.905×10^3	25.3

If we take account of the finite age of the earth, assuming it to be 5×10^{16} seconds, and use the solution for a cooling body the surface of which is maintained at constant temperature, zero, and which contains radioactive material assumed to diminish exponentially with depth,¹⁸ we shall have to decrease these figures by about 11.5 per cent, giving us

Rock	Depth in km.
granite	21.35
diorite	20.55
basalt	22.4

Jeffreys¹⁹ from radium and thorium data calculated the thickness of the granite crust to be 15 km. and Joly²⁰ calculated it to be 31 km. Here, however, both of these men used their calculations as arguments in support of their respective theses

$$0.00404 + 0.000\ 019 \left(\frac{P}{1000} \right) \text{ cal/sec/cm}^2 \text{ at } 75^\circ$$

$$0.00414 + 0.000\ 008\ 9 \left(\frac{P}{1000} \right) \text{ cal/sec/cm}^2 \text{ at } 30^\circ$$

where $P = \text{kgm/cm}^2$.

The data of Herschel and Lebour (5 specimens) and Peirce (2 specimens) give an average value of 0.0035 for the thermal conductivity of trap. See ref. for (13).

Jeffreys (Geol. Mag. 63, p. 518, 1926) cites these results of Bridgman as evidence for his statement "Bridgman's experimental work (above data) has shown that the thermal conductivity probably increases somewhat with depth."

According to Bridgman's data the pressure effect due to an increase in pressure of 20,000 kgm/cm² (corresponding to depth of about 70 km.) is an increase in conductivity of 0.0004, but the same data show a decrease in conductivity of 0.0001 for an increase of 35°C. in temperature. Hence Jeffreys' inference appears not to be entirely justified. The probability is rather that the thermal conductivity decreases with depth. See also H. H. Poole, Phil. Mag., Jan. 1914.

¹⁸ Ingersoll and Zobel, Math. Theory of Heat Conduction, eqn. 85, p. 95; see also Adams, L. H., Jour. Wash. Acad. Sci., 14, 470, 1924.

¹⁹ Monthly Notices Royal Astronomical Society, Geophys. Suppl. I, 1926, p. 386; also Beitr. z. Geophys. 15, 170, 1926. In a more recent calculation Jeffreys (Beitr. z. Geophys. 18, 6, 1927) makes the granite layer 11.5 km. thick.

²⁰ Gerl. Beitr. z. Geophys. 15, 189-200, 1926; The Surface History of the Earth, 1925, pp. 66-73. In this calculation he appears to have used a wrong value for the energy of decomposition of radium.

and hence may be guilty of special pleading. Jeffreys' thesis is that the granitic crust is from 12 to 15 kilometers thick and Joly's that it is 31 kilometers thick. L. H. Adams²¹ obtained 20 kilometers as the thickness of the granite layer, using Jeffreys' value of the heat produced in the surface layer but different heat-conductivity data.

Errors involved in such a calculation.

(1) There are experimental sources of error in determining the amount and the energy of decomposition of these substances and there is much uncertainty about the representative character of the rock samples measured. The determination of the amount of radium and thorium in rocks may be in error one hundred per cent.

(2) We assumed that these radioactive substances decrease with depth. We are reasonably certain that qualitatively this is so, since our geological and physical data indicate that basic rock underlies the "granitic" rock, and basic rocks contain less potassium, radium and thorium. Now if this assumption be true then any hypothesis of decrease with depth will give nearly the same result whether we make the rate of decrease obey an exponential law or whether we assume the amounts of potassium, thorium, and radium to be constant over a certain thickness.

(3) We assumed that all the energy given off by the decomposition of these radioactive substances was converted into heat. J. W. Evans²² criticizes this assumption, stating that it is probable that a considerable part of the energy liberated by these radioactive substances is used up in effecting physical, chemical, or atomic changes in the surrounding constituents of the rock. This statement has been adversely criticized by many people on the ground that the calculated and experimentally determined heat of decomposition agree very closely. In these experimental determinations, however, the only substance that the rays come in contact with is the glass container. Even in this there is evidence of chemical action, for the tube becomes intensely colored. Thus the above syllogistic argument seems not entirely justified.

(4) We assumed the rate of decomposition to be constant. This assumption is based primarily on the coincidences

²¹ Jour. Wash. Acad. Sci. 14, 471, 1924.

²² Quart. Jour. Geol. Soc. 2, 60, 1926.

between lead-uranium ratios and the geological age relationships of the rock hosts. We are unable, however, to prove that all of the lead present is a decomposition product of uranium. In many cases it has been shown that in all probability it was not so. This assumption is therefore not so well established that we may take it for granted.

c. Seismological evidence. One of the few sources of direct data relative to the interior of the earth is provided by interpretations of seismological records. Geologists, in building up theories of the earth's interior, have therefore used these interpretations by the seismologists as though they were incontrovertible facts.

Although most of our knowledge of the earth's interior will come from this source, nevertheless we should not lose sight of the fact that the data themselves need refining by decreasing the experimental errors; that the mathematical development used in the computations is based on hypotheses some of which the data themselves are not accurate enough to establish with certainty, and furthermore the data indicate that the laws of reflection and refraction assumed for the mathematical computations are not obeyed exactly; that our knowledge of the physical characteristics of the prevailing rocks and minerals is far from being complete and is capable of greater accuracy.

Seismologists realize this and are striving for more accurate data and more trustworthy interpretations of these data, but sometimes we who are less familiar with the details of their work do not realize this as fully as we should.

If the reduced time-distance²³ curves of S. Mohorovičić²⁴ be accepted, then from these data we find that the velocity of the P_g waves, the compressional wave traveling in the "granitic" layer, increases from 5.54 km. per second at the

²³ A time-distance curve, say for a $\bar{P}$ or P_g wave, which is the compressional wave traveling in the uppermost or "granitic" layer, is obtained by plotting the times at which this shock is recorded against epicentral distance Δ measured on the earth's surface. The epicenter is the point at which the radius through the origin or focus of the earthquake cuts the earth's surface. Zero time is the time the ray reaches the epicenter. In the "reduced time curve" the focus coincides with the epicenter. Since seismographs which record these shocks are sparsely scattered geographically and since earthquakes occur usually at some depth below the surface, no single earthquake can give a complete record, hence any reduced time curve must be a composite of many earthquake data. The slope of the curve gives the apparent

velocity of the ray, $v_\Delta = \left(\frac{d\Delta}{dt} \right)$ at the distance Δ considered.

²⁴ Gerl. Beitr. z. Geophys. 13, 231-240, 1914.

surface to 5.8 at about 60 km. At about 60 km. the Mohorovičić²⁵ find a marked discontinuity, the velocity of the compressional waves jumping to 8.0 ± 0.2 km. per second. These data would thus indicate that the rock has the physical characteristics of a granite down to a depth of 60 km.

S. Mohorovičić has, however, extrapolated his reduced time curve beyond the data. The maximum distance at which P_0 is recorded seems to be about 700 km. A ray traveling this epicentral distance will dip down 40 km. at its apex (deepest point of its path).

In analyzing the data from the Tauern earthquake Conrad²⁶ finds, apparently, a compressional wave, which he calls P^* , traveling in a layer lying between the granitic layer and the layer below the marked discontinuity in which the wave called P or P_n travels. This ray is recorded between $\Delta = 226$ and $\Delta = 552$ km. and has an apparent surface velocity of 6.22 to 6.23 km. per second. Conrad also finds that the best approximation of the focal depth is 26 km. From these data we find that the intermediate layer lies between the depths 40 and 64 km. The velocity of the compressional wave in this layer ranges from 6.15 at 40 km. depth to 6.17 at 64 km. depth.

Jeffreys²⁷ obtained 12 ± 4 km. for the thickness of the granitic layer and 25 ± 4 km. for the intermediate or "basaltic" one. In these calculations he has made many extrapolations and approximations. Some of them, though theoretically not correct, do not materially affect his conclusions. The chief discrepancy occurs in the assumption that the foci or origin of the earthquakes he investigates lie on the surface of the earth. The focal depth of the Tauern and the Stuttgart earthquakes cannot be calculated to any great degree of accuracy, but that is no valid reason for ignoring such determinations. Gutenberg²⁸ obtained 30-35 km. as the focal depth of the South German earthquake of 1911, and Conrad²⁹ obtained an average of 26 km. for the Tauern earthquake of 1923. If such values for the focal depth were accepted then the value for the thickness of the granitic layer must be increased to

²⁵ A. Mohorovičić, *Tables de A. Mohorovičić*, Bureau Central Séismologique International, Paris 1925, obtains 57 km. S. Mohorovičić, *Gerl. Beitr. z. Geophys.* 13, 239, 1914, obtains approximately 60 km. as the depth under Europe; this value he says can be less.

²⁶ *Mitt. d. Erdbeben-Kommission* 59, 1-23, 1925.

²⁷ Jeffreys, Harold, *Monthly Notices Roy. Astronom. Soc., Geophys. Suppl.* 1, 385-402, 1926.

²⁸ *Gerl. Beitr. z. Geophys.* 15, 62, 1926.

²⁹ *Mitt. d. Erdbeben-Kommission* 59, 1-23, 1925.

about 35 or 40 km. Thus if Jeffreys' determination of the thickness of the granitic layer be modified following the suggestions just offered, and the resulting value added to his thickness of the "basaltic" layer, the depth of the major discontinuity will be more in accordance with that determined by the Mohorovičićs and others.

Geological evidence tells us that sudden transitions or "discontinuities" are improbable. None the less, geologists have given to the seismologists' term "discontinuity" the technical meaning now used by geologists, namely, that transition might take place in a zone only a few meters thick.

Now the period of these *P* waves is somewhere about 10 seconds, which gives us, assuming a velocity of 6 km. per sec., a wave length of 60 kilometers. Thus if the transition from material transmitting *P* waves with a velocity of 6.2 km. per sec. to material transmitting *P* waves with a velocity of 7.8 km. per sec. extended through a zone several km. thick, seismological records would still indicate a sharp discontinuity. This affords the geologist ample leeway for any acceptable postulate of continuous change in the material that transmits these waves.

The transition from granite to rock with the characteristics of diorite or basalt⁸⁰ will necessarily be gradational, otherwise reflected waves would occur at this transition zone and be recorded on the Oppau records. No trace of these is found, according to Jeffreys. The same is true of the transition to the zone which transmits the normal *P* waves.

Jeffreys⁸¹ determination of 15 km. as the depth of the granitic layer based on the dispersion of "Love waves" or "Querwellen" does not seem to deserve the importance that he attaches to it.

As a summary we may say that seismologic evidence points to a major discontinuity at a depth of about 60 kilometers. There is also evidence of a less distinct intermediate discontinuity at a little over one-half this depth, which we may tentatively place at about 40 kilometers depth. Data on the lateral distribution of density are very scanty and will remain so

⁸⁰ Jeffreys calls this internal layer basalt. L. H. Adams (Adams and Gibson, Proc. Nat. Acad. Sci. 12, 282, 1926), from compressibility measurements on a tachylite from Kilauea (density 2.85), obtained a velocity for the longitudinal wave of 6.45 km. per sec. The effect of increasing temperature with depth on the velocity of earthquake waves is not known, since we do not know quantitatively its effect on the rigidity and bulk modulus, but it may be sufficient to account for the discrepancy here.

⁸¹ Monthly Notices Roy. Astronom. Soc., Geophys. Suppl. 1, 1925.

until systematic field programs can be carried out. We have, however, sufficient data to indicate that the density of the rock underlying the Pacific ocean is greater than the average density of continental rock. For example, Angenheister⁸² found for the Pacific ocean in the neighborhood of the island of Apia that the velocity of the *S* (transverse) waves was about 18 per cent greater in the upper 60 kilometers than the corresponding wave velocities for Asia (or California). Gutenberg's⁸³ analysis of the Apian and Japanese earthquake records indicates too that apparently no *P_o* waves arrive from earthquakes in the Pacific. These men, and other seismologists, thus find that the granitic layer which is about 35 to 40 kilometers thick in Europe, is either wholly lacking or else is very thin under the Pacific. The density of the sub-Pacific material thus corresponds to a "basaltic" rock.

In summing up our knowledge of density distribution we find that the conclusions arrived at from radioactive data and heat conduction do not check very well with those obtained from geological and seismological data. The errors and unknown variables involved in arriving at the conclusions obtainable from radioactive data are such at the present time that we can not give to these results equal weight with those obtained from the combined geological and seismological investigations. The conclusions from the last two indicate that to a depth of about 60 or 65 kilometers the sub-Pacific rock is femic in character and has a density in the neighborhood of 3.00; that the continental rock, on the other hand, is salic in character to a depth of about 30 to 40 kilometers and underlain by a more femic material 30 to 20 kilometers thick.

2. *Depth of Compensation.*

It seems to the writer that the only logical conclusion that can be drawn from the data at hand is that the center of gravity of isostatically compensated rock columns varies with the surface load and heterogeneity in vertical and lateral density. How, otherwise, are we to explain mountain building with the formation of geosynclines some of which are more than 25 kilometers thick, the tremendous lateral shifts of rock loads which these figures entail, and the lateral movements during folding? Following this we may then invoke thermal expansion which may even be the *causa sine qua non* of uplift

⁸² Angenheister, G., Nachrichten der K. Ges. Wiss. Göttingen, 1-34, 1921.

⁸³ Gutenberg, B., For references see Der Aufbau der Erde, 99, 1925.

after folding. This is the thesis that Daly and others have put forth. It seems probable that isostatic adjustment by means of sinking takes place faster than thermal adjustment by conductivity and thus temperature gradient lags behind. The final adjustment of the thermal gradient could then give sufficient dilatation to push the folded rocks to the altitudes we gaze and marvel at. This is, to the writer, the only explanation of mountain uplift that is at all satisfying.

Even the statistical analyses of gravity data on the most probable depth of compensation carried out by the Coast and Geodetic Survey favor this conclusion. These analyses indicate that a direct relation between topography and depth of compensation exists, being deeper under mountain regions and shallower under low-lying regions.

Since calculations of isostatic compensation must be referred to a datum, we require some chosen column as our arbitrary zero of reference. The column that has been used as a standard by the U. S. Coast and Geodetic Survey and by Heiskanen is a continental column at sea level elevation. We shall assume here as a standard an oceanic column consisting of 4 kilometers of water underlain by basic rock and compare this with various possible continental columns at sea level.

It should be borne in mind, however, that gravity data alone are not able to discriminate between hypotheses made as to depth of compensation. This has been pointed out by Jeffreys.³⁴

Two alternative standard columns are assumed:

- (1) 4 kilometers of water (density 1.03) underlain by rock of density 3.0,
- (2) 4 kilometers of water underlain by rock of density 3.1.

Since topographic corrections applied outside a zone of 25° radius are the same for each station within the limits of error involved and will thus balance out, computations are carried out only to this distance.

The data below represent three determinations made by Dr. Meinesz in his 1926 submarine trip in the Pacific ocean. Their location, depth, and observed gravity values are:

<i>Pacific Ocean</i>			
Sta.	latitude, longitude	Depth. meters	Observed g.
109	28° 57.3', 141° 15.8'	4956	979.270
111	25° 46.2', 147° 42.7'	5212	979.036
113	22° 57.4', 153° 41.1'	4572	978.880

³⁴ Jeffreys, Harold, *Gerl. Beitr. z. Geophys.* 15, 167-188, 1926.

Using an oceanic column consisting of 4 km. depth of water and suboceanic crustal densities of 3.0 and of 3.1 as standards for the topographic correction, the calculated values of g and the differences between the observed and calculated values are

Sta.	γ_0	topog. corrn.		calc. g .		$g_{\text{obs.}} - g_{\text{calc.}}$	
		$\rho_{\text{suboc.}} = 3$	$\rho_{\text{suboc.}} = 3.1$	$\rho_{\text{suboc.}} = 3$	$\rho_{\text{suboc.}} = 3.1$	$\rho_{\text{suboc.}} = 3$	$\rho_{\text{suboc.}} = 3.1$
109	979.240	+ .054	+ .049	979.294	979.289	— .024	— .019
111	979.006	+ .022	+ .015	979.028	979.021	+ .008	+ .015
113	978.815	+ .041	+ .034	978.856	978.849	+ .024	+ .031
average						+ .003	+ .009

The following table gives a number of continental stations in the United States near sea level with the observed and calculated gravity attractions and the differences between the two.

TABLE 2.

Station	elev. meters	g_{observed}	γ_0	topog. and elev. corrns.	$g_{\text{calc.}}$	$g_{\text{obs.}} - g_{\text{calc.}}$
1. Key West, Fla.	1	978.970	978.922	— .025	978.897	+ .073
7. Galveston, Tex.	3	979.272	979.267	— .023	979.244	+ .028
18. Beaufort, N. C.	1	979.729	979.706	— .024	979.682	+ .047
21. Washington, D. C. 14 (Coast and Geod.)	14	980.112	980.067	— .020	980.047	+ .065
315. Crisfield, Md.	1	979.985	979.987	— .021	979.966	+ .019
average						+ .046

Thus if we balance a continental column of zero elevation against an oceanic column of radius 25° we can determine the thickness of light subcontinental rock that will give a difference in gravity attraction of +0.043 (suboceanic $\rho = 3.0$), and of +0.037 (suboceanic $\rho = 3.1$) dynes for the continental mass assuming that below this depth the rock material is of the same density in each column.

The following table gives the columns of granitic rock which will give the corresponding gravitative differences for different densities; the columns necessary for isostatic equilibrium are also listed.

TABLE 3.

Subcontinental density	Suboceanic $\rho = 3.0$		Suboceanic $\rho = 3.1$	
	Depth for isostatic balance km.	Depth for gravity measurements km.	Depth for isostatic balance km.	Depth for gravity measurements km.
2.7	26.2	26.2	20.7	21.0
2.73	29.2	30.0	22.4	23.1
2.75	31.5	31.6	23.7	23.9
2.8	39.4	39.6	27.6	28.0
3.0	79.0	79.6	41.4	42.0

The gravity data indicate that a continent at zero elevation would be balanced isostatically for any reasonable density distribution; the depth of compensation being dependent on the density assumed or determined.

In this calculation the hypotheses assumed were that the sub-Pacific rock is femic in character and that the granitic continental rock extends to some finite depth at and below which depth the density is a function of depth only. A reasonable density distribution would be 2.7 to 2.8 which would make the granitic shell 26 to 40 km. thick. This range of values is also in good agreement with that deduced from geological and seismological data.

3. *Strength of the earth's crust.*

The capacity of the crust to resist vertical stresses is an important factor in any hypothesis which pretends to explain isostasy. For this we need to know the largest topographic feature that can be sustained by virtue of the strength of the crust.

Hayford considers that isostasy is largely complete in areas between one square mile and 430 square miles, the mean departure of these unit areas from the level of complete isostatic equilibrium ranging from 250 to 570 feet, which represents the maximum elevation of uncompensated load such an area could have and yet remain stable. He does not give these figures as anywhere near accurate, the emphasis being directed to show that isostatic compensation is nearly perfect.

a. *General considerations on the strength of the crust.* Experiments of Michelson⁸⁵ and others, and calculations based on tidal distortion⁸⁶ indicate that the earth has a high order of rigidity, but their results do not solve our present problem.

Geologic data on the yielding of the crust itself are of more importance. Joseph Barrell⁸⁷ has attempted to reach a solution of this problem based on geologic and geodetic data. In these articles he cites many instances, e. g., the Nile and Niger deltas, which indicate a strength of the crust in excess of that deduced from Hayford's statement. Other cases of probably uncom-

⁸⁵ Michelson, A. A., and Gale, H. G., Jour. Geol. 27, 585, 1919; Nature 104, 114, 1919; Astrophys. J. 50, 330-345, 1919.

⁸⁶ Jeffreys, Harold, Monthly Notices Roy. Astronom. Soc. 75, 648-58, 1915; 76, 86-9, 1915; 77, 449-56, 1917; Geophys. Suppl. I, 412-424, 1926.

⁸⁷ Jour. Geol. 22, 28-48, 145-165, 209-236, 289-314, 441-468, 537-555, 655-683, 729-741, 1914; 23, 27-44, 1915.

pensated loads on the crust which would support Barrell's thesis are the relatively recent volcanic islands in the Pacific.

We have also cases of non-support such as the down-warping of the northern part of North America during the time of the Pleistocene ice loads, which is now rising with respect to the sea level presumably in the direction of hydrostatic balance. Since we do not yet know the mechanics of igneous intrusion we can not cite as examples the down-warping following the extrusion of the Columbia River basalts, the intrusion of the Sudbury lopolith and other similar cases.

Let us consider the island of Hawaii. The assumption that the island is unsupported isostatically, i.e. that it is not a compensated mass, agrees well with geological data and, as will presently be shown, with geodetic data.

The pressure exerted on the ocean floor by the island of Hawaii would be 682 kilograms per square centimeter over an area of 49,106 sq. km. This would correspond to a load of 2,520 meters of continental rock over an area of 125 kilometers radius.

Downfaulting and sinking around the island and sinking of older islands to the northwest of it indicate that this load may represent a limiting strength of the crust. If this inference were accepted we would then have a value for the strength of the crust lying between that reached by the hypothesis advanced by Hayford and the conclusion arrived at by Barrell, but much nearer the latter.

In regions of high relief it is possible to obtain from gravity data some conception of the sizes of topographic features that the crust can sustain, provided the gravity stations are sufficiently numerous. Calculations have been made for some of these regions and the results listed in Table 4, which are seen to agree with the conclusion that the strength of the crust lies somewhere between the values assumed by Hayford and Barrell.

IV. APPLICATION TO GRAVITY VALUES IN THE UNITED STATES.

The next step is to see whether an hypothesis satisfying the preceding data also gives values which are in agreement with the observed gravity values.

We shall assume that a continental mass of zero elevation is compensated isostatically at a depth of 29 kilometers in conformity with the conclusion on p. 111; and that the difference

TABLE 4

No. Sta.	Name Sta.	Lat.	Long.	Elev. meters	Airy hyp. calculation					Calc. anomaly for mean depth	Pratt anomaly
					Depth compn. I	Calc. anomaly for zero radius	Depth compn. for mean anomaly	Calc. anomaly for mean depth	Pratt anomaly		
					km.	II	km.	V	VI		
69	Grand Canyon, Ariz. ...	36 05.3	112 06.8	849	15.4	+.003	15.0	-.005	-.002	.005	
68	Yavapai, Ariz.	36 03.9	112 07.1	2179	18.3	+.035	14.1	+.003	+.009		
65	Yuma, Ariz.	32 43.3	114 37	54	.83	+.013	0.5		+.017		
76	Bismarck, N. Dak. ...	46 48.5	100 47	516	5.32	+.035	1.6	+.008	+.010	.028	
188	Marmarth, N. Dak. ...	46 18.4	103 53	822	8.33	+.050	2.9	-.001	+.043		
187	Faith, S. Dak.	45 01.3	102 04	786	7.58	+.036	3.7	-.013	+.023		
201	Wasta, S. Dak.	44 04.2	102 25	706	7.43	+.041	3.0	-.002	+.038		
269	Hill City, S. Dak.	43 55.9	103 34.1	1518	14.85	+.080	6.0	-.003	+.042	.033	
202	Moorecroft, Wyo.	44 15.5	104 58	1295	12.9	+.043	8.3	+.012	+.029		
270	Newcastle, Wyo.	43 51.4	104 11.8	1328	13.33	+.050	7.8	-.008	+.029		
273	Boulder, Colo.	40 01.2	105 16.6	1630	18.43	-.016	20.2	-.015	-.014	.013	
274	Lafayette, Colo.	39 59.8	105 05.2	1595	17.7	-.008	18.6	-.001	-.020		
275	Brighton, Colo.	39 59.3	104 48.9	1511	16.0	+.002	15.8	+.023	-.006		
276	Idaho Springs, Colo. ..	39 44.6	105 31.1	2303	24.9	+.045	19.4	-.007	+.022		
79	Boise, Idaho	43 37.2	116 12.3	821	9.67	+.011	8.4		+.016		
59	Pembina, N. Dak.	48 58.1	97 14.9	243	2.5	+.029	0.6		+.027		

in density between an oceanic column and a continental column is 0.28.

The initial assumption made in calculating the gravity anomalies in the foregoing table, according to the hypothesis of Airy, is that compensation is complete in areas of 170 kilometers radius (columns I and II). The depth of compensation is that calculated for zero anomaly on this assumption (column III).

In the calculation of compensation the same method that Heiskanen uses is adhered to in calculating the outer zones, i.e. the zones lying between the radii 170 km. and 20,012 km. measured on the earth's surface. It is done to simplify calculation and this approximation is found to lie within the limits of error involved.

Finally, stations are grouped in larger areas (column IV) giving much smaller anomalies (column V) than those from the initial assumption. This would indicate that compensation extends farther areally, at least in some cases, than the initial assumption of 170 kilometers radius.

The gravity anomalies given in column V are smaller than those given by the Pratt-Hayford hypothesis (column VI).

We thus have a form which will satisfy gravity data as well, at any rate, as the Pratt-Hayford hypothesis. Moreover, it is in much better accord with geophysical data.

The assumptions are admittedly only first approximations. For example, we should take into account the variation of density in depth dependent on change of character and state, on compressibility and on thermal expansion. Such attempts at refinement must, however, wait for additional physical data.

V. APPLICATION OF THE HYPOTHESIS TO THE PACIFIC ISLANDS, IN PARTICULAR TO HAWAII.

Accepting the form of Airy's hypothesis proposed, in which an oceanic column represented by 4 km. of water underlain by femic rock is assumed as a standard column, determinations made on oceanic islands and plateaus on the ocean floor should have a positive gravity anomaly with respect to this column, and this is roughly what we find. That is, volcanic and coral islands in the Pacific will be unstable, and will approach stability, according to the present concept of isostasy, by sinking. This, incidentally, would explain the sinking, relative to the sea level, of coral islands and would thus provide a neces-

sary condition for their formation without recourse to complex mechanisms such as have previously been used in explaining this phenomenon.

The large anomalies left in the island of Hawaii after correcting according to the Pratt-Hayford hypothesis present an interesting problem which should be capable of a simple explanation if the theory of isostasy can explain the difference of gravitational attraction on the earth. According to Hayford and Bowie's³⁸ computations we have an anomaly of $+0.183$ dynes at Mauna Kea after correcting for topography and isostatic compensation.

Preston,³⁹ using the so-called Bouger or Young's formula, the derivation of which is given under correction for topography (p. 95), calculates a density for Hawaii of 3.26 on the assumption that the mean density of the earth is 5.58.

A density of 3.26 can certainly be discarded immediately. Washington⁴⁰ gives an average value of 2.96 for the density of the rock material. The flows are, however, all more or less vesiculated, which will very materially lower the average density; for example, E. S. Shepherd obtained 2 for the density of a block of compact vesicular basalt selected as typical material for the usual pahoehoe flow. The vesiculated basalt is interbedded with loose ash beds which may well contain as much as 30 per cent of open space. Hence 2.96 will represent an upper limit for the density of the island with a probable average density much below this.

The following table (Table 5) gives the data used in the present analysis. The last column shows the amount of the correction for the topographic attraction and the attraction of an increase or decrease in density of the substratum under the assumption of isostatic compensation.

The observed gravity value of Kalaieha, in the saddle between Mauna Loa and Mauna Kea, is 978.485 cm/sec.² The corrections for the latitude and elevation of Waiau, the top of Mauna Kea, to be added to this value are $+0.0066$ and -0.6021 respectively, giving a corrected value of 977.89. The observed gravity value of Waiau is 978.055. Thus the topographic correction to be applied between the elevations of

³⁸ Hayford, J. F. and Bowie, William, U. S. Coast and Geod. Survey, Sp. Pubn. No. 10, 80, 1912.

³⁹ Preston, E. D., Appendix No. 12, Report for 1893, U. S. Coast and Geodetic Survey, 630, 1894.

⁴⁰ Washington, H. S., Jour. Wash. Acad. Sci. 13, 454, 1923.

TABLE 5.
*Island of Hawaii**

Place	Latitude	Elevation in meters	g observed	γ^0	Corrn. for elev.	T^0
Kawaihae ^a	20° 02' 5.9"	2.4	978.799	978.644	.....	+ 0.
Kalaieha ^a	19° 42' 2.6"	2030	978.485	978.625	0.62646	+ 0.
Kilauea ^b	19° 25.9'	1211	978.667	978.609	0.3737	+ 0.
(Volcano Observ.)						
Waiau ^a	19° 48' 52"	3981	978.055	978.631	1.2285	+ 0.
(Summit Mauna Kea)						
Mokuaweoweo ^b	19° 29.8'	3970	978.091	978.613	1.225	+ 0.
(N. lip Mauna Loa crater)						
Hilo	19° 44.0'	5	978.878	978.626	.002	+ 0.

* The relative positions of the stations are indicated on the accompanying map of Oahu, Maui and Hawaii.

^a Preston, E. D., *ibid.*

^b The Volcano Letter, January 13, 1927. The value given for Mokuaweoweo in the Letter is 979.091. This is obviously a misprint and should be 978.091.

^c The values of γ used here are calculated from the Bowie formula No. 2, U. S. Coast and Geodetic Survey, Sp. Publ. No. 40, 134, 1917.

Waiau and Kalaieha is +0.1655 dynes if we neglect the upward pull of the mountain mass on the station at Kalaieha.

Now if we assume that the topography between Waiau and Kalaieha can be represented as a cone of height 1,951 meters and base radius of 22,531 meters with Waiau as apex we obtain 2.12 as the density of the rock in this cone.

The observed gravity value at Kilauea (Volcano Observatory), elevation 1,211 meters, is 978.667 cm/sec.² The corrections for the latitude and elevation of Mokuaweoweo to be added to this value are +0.0037 and -0.851 respectively, giving a value of 977.820. The observed gravity value at Mokuaweoweo, 2,760 meters higher, is 978.091. Thus the topographic correction to be applied between the elevations of Mokuaweoweo and Kilauea is +0.271 if we neglect the upward pull of the mountain mass on the station at Kilauea.

Assuming that we can represent the topography between Kilauea and Mokuaweoweo as a cone of height 2,759 meters and base radius of 39,083 meters with Mokuaweoweo as apex, we obtain 2.52 as the density of the rock in this cone.

Let us assume that the whole island can be represented as a cone, with Waiau as apex, of height 76×10^4 cm. above the sea floor and radius 125×10^6 cm. on the sea floor, and that the underlying portion of the crust is the same as that underlying the Pacific as a whole, i.e. the observed gravitative attraction would be normal at sea level if the island were non-existent.

The attraction of this island mass on a mass of one gram at Waiau will then be $+0.6524$ dynes.

Assuming uniformity, we obtain a density of 2.69 for the whole island cone after correcting for the attraction which a mass of sea water, density 1.03, equal in volume to that of the cone below sea level, would have.

It is very improbable that the whole mass be of uniform density, a more probable assumption being that the density increases with depth. Compaction by pressure and the intrusion of basic sills and dikes will undoubtedly increase the density of the lower material. Moreover we have just seen that the gravity values for both Mauna Kea and Mauna Loa show that the upper cone is much less dense than the average value for the island. If we assume the density of the material below sea level to be 2.95 (giving, on subtracting the density of sea water, an effective density of 1.92) we obtain 2.44 as the density of the whole mass above sea level; if we assume the density of the material below sea level to be 2.75 (giving an effective density of 1.72) we obtain 2.625 as the density of the portion above sea level.

In obtaining these values we have assumed that the mass was wholly uncompensated isostatically. Geologic evidence is in favor of this assumption, for Hawaii is composed of the same material as has been assumed to underlie the Pacific.

On this assumption, then, to achieve isostatic equilibrium the whole island would sink 3,100 meters, assuming it now to have an average elevation of 915 meters (3,000 ft.). This would leave Mauna Kea a relatively low mountain of 862 meters (2,830 ft.) elevation above sea level. This is the solution assuming zero strength of the crust and the figure thus represents an upper limit. The proper value of the amount of sinking of the island will lie somewhere between 3,100 and zero meters.

The calculations of densities and limiting values between which sinking might be expected are based on necessarily approximate estimations of the topographic features; more accurate deductions must wait until a contour map of the island and neighboring ocean floor becomes available.

If the island were stable, i.e. no sinking would occur, the crust must be rigid for uncompensated loads in excess of 682 kgm. per sq. cm. over areas of 49,100 sq. km. Now an examination of the past histories of the older islands of this group shows that they have subsided.

For example, from a study of the fauna, H. A. Pilsbry⁴¹ comes to the following conclusion: "The Hawaiian area from northern Hawaii to and probably far beyond Kauai formed one large island which was inhabited by the primitive *Amastrinae*. This pan-Hawaiian land, whatever its source, preceded the era of vulcanism which gave their present topography to the islands and probably dated from the Palaeozoic. . . . Volcanic activity built up the older masses, subsidence following, Kauai being the first island dismembered from the pan-Hawaiian area. . . . Northern Hawaii was next isolated by formation of the Afenuihala Channel, leaving the large intermediate island which included the present islands of Oahu, Molokai, Lanai and Maui."

Bryan states:⁴² "In addition to all else the evidence of the wonderfully dissected mountains, the deeply eroded valleys, the submerged coral reefs, all tend to bear out the broad conclusion that the group has evolved by the submergence of a single island, and that the isolation of the existing islands with their peculiar, yet related plants and animals, have been formed as superimposed volcanic remnants on the older and deeply subsided larger land area."

Charles H. Hitchcock⁴³ similarly reaches the conclusion that much subsidence has taken place.

Kauai, according to Hitchcock, is older than the other islands. It has a maximum elevation of 1,600 meters. The highest point of Oahu, the most westerly large island of the group, is Mt. Kaala, 1,230 m. elevation; off Molokai is Kama-kon, 1,510 m. elevation. Maui is the nearest large island to Hawaii. The maximum elevation of west Maui, the oldest part of the island, is Puu Kuku, 1,768 m.; of east Maui is Pukaoaa, on the edge of Haleakala, 3,060 m.

Even in Hawaii, the youngest of the group, normal faulting with subsidence has been observed.

On going to the northwest from the island of Hawaii we find that the peaks in the group, excepting the islands of Nihoa and Kauai to the north, are progressively lower. Moreover the gravity anomaly becomes greater as we go westward from Honolulu to regions where vulcanism is still active.

If we accepted Mauna Kea as the maximum height attainable and assumed that these several peaks reached this height when in their glory, then Oahu, the northwestern island, has

⁴¹ Bryan, W. A., *Natural History of Hawaii*, Honolulu, 123, 1915.

⁴² Idem, p. 124.

⁴³ *Hawaii and its Volcanoes*, 1911.

sunk about 2,990 meters (9,795 ft.), Molokai about 2,700 meters (8,867 ft.), the western part of Maui 2,450 meters (8,037 ft.), and the eastern part of Maui 1,155 meters (3,789 ft.). On the basis of this logic Hawaii should sink about 2,500 meters (8,202 ft.). This would leave Mauna Kea 1,462 meters (4,680 ft.) elevation.

Geological observations of the Fiji and Samoan islands indicate that the same sort of thing is going on in these groups. For example, W. M. Davis⁴⁴ says of the Fiji islands, "The more closely the geological history of Fiji is investigated, the more clearly is it seen that Darwin's theory of reef (coral) formation is merely a generalization of those phases of Fiji history in which subsidence permitted reefs to be built up." and "The phases of the western belts occur later than the corresponding phases of the eastern belts; and this clearly suggests the westward propagation of a broad and shallow wave-like deformation of the ocean floor."

Heiskanen⁴⁵ has calculated, according to the Pratt-Hayford method of reduction, the gravity anomalies for 80 stations on the Japanese islands and finds that the average is $+0.020$ cm. per sec² after correcting for assumed isostatic compensation, the anomaly increasing in value in the group from south to north. Here, too, the geodetic evidence indicates that this group of islands is in part an uncompensated load on the earth's crust which is here the sub-Pacific rock.

As a summary of these results it may be said that the limiting range of densities for the mountains of Hawaii is 2.4 to 2.63, the lowest value given being the most probable. These figures were obtained on the assumption that the island of Hawaii is an uncompensated load on the sub-Pacific crust. An immediate consequence of this assumption is that to achieve isostatic equilibrium the island would sink 3,100 meters. The crust must, however, have some finite value of rigidity greater than zero so that the amount of sinking would be less than this figure. The older islands of the Hawaiian group have subsided and if they in their youth towered as high as Hawaii then the sinking of this island will be about 2,500 meters. Not so much is known about the other volcanic islands of the Pacific but where information is available it indicates that they are uncompensated and that submergence is or has been taking place.

⁴⁴ This Journal 14, 333-351, 1927.

⁴⁵ Zeitschr. f. Geophys. 3, 213-16, 1927.

In order to determine the validity of these conclusions more data are necessary, including measurements of the gravitative attraction at sea and at strategic points on the Pacific islands, accurate contour maps of the ocean floor and of the islands investigated, and more geological data on the rock character and past history of the islands. This is being supplied gradually; for example there will soon be available the gravity measurements of Meinesz in the Pacific and a topographic map of the island of Hawaii.

It has also been seen that seismology can serve as an invaluable tool in establishing sound hypotheses on the nature of the crust. Before it can be used as such it is necessary to secure more abundant and more accurate data. The mathematical development is based on the simple laws of refraction and reflection which are known not to be obeyed exactly, some of the discrepancies being due probably to the heterogeneity of the crust causing diffraction and internal reflections. It is thus desirable to determine the deviations from the simple equations used and formulate more accurate expressions. The data are also incomplete, resulting in much extrapolation, with consequent uncertainties in the conclusions drawn.

VI. CONCLUSION.

After considering the physical and geological restrictions which any hypothesis for computing isostatic compensation must satisfy, the writer adopted, as being the most acceptable, a form of the Airy hypothesis which was later found to be in very good agreement with that proposed by Heiskanen.

In Airy's own presentation he used the word "lava" for his substratum. Some have stumbled over this word and refused to go farther, but it is not necessary to postulate a molten substratum in order to substantiate his general hypothesis.

These results indicate that a continent at sea level is compensated at about 30 kilometers depth with respect to the sub-Pacific crust, regions of higher elevation at correspondingly greater depths, and that the sub-Pacific crust differs from the continental crust in being uniformly femic down to a depth of about 60 kilometers.

The inference is, too, that the volcanic islands of the Pacific are essentially uncompensated (sinking) loads on the sub-Pacific crust.

DETERMINING THE FIGURE OF THE EARTH BY TRIANGULATION.

JOHN F. HAYFORD.

INTRODUCTORY NOTE.

The following articles by the late John F. Hayford were recently found in the files of the U. S. Coast and Geodetic Survey. Nothing is known at the Coast and Geodetic Survey regarding the occasion for which these articles were written or the journal, if any, for which they were intended. Obviously they are not exhaustive monographs but brief notes designed to emphasize a single point that seemed to Mr. Hayford to need emphasis. Except for a few minor typographic corrections the papers are printed just as Mr. Hayford left them after revising them in his own handwriting.

Even to-day these brief papers are still timely. The first article, entitled "It is not Necessary to Place Geodetic Arcs in Various Latitudes," was probably intended to answer certain objections to Hayford's 1909 values for the figure of the earth, now adopted as the basis of the international ellipsoid of reference. The objection, answered in his paper, that Hayford's results were deduced from observations covering only a comparatively small range of latitude, is sometimes raised even to-day. There is the further possible objection, not mentioned by Hayford, that his argument is true only if the earth is very closely a mathematically regular ellipsoid of revolution and that this can be proved or disproved only by observations covering all accessible parts of the globe. This objection is at least partially met by Heiskanen's recent work on European triangulation.¹

The second paper, entitled "The Ellipticity of the Earth is not a Proof of a Former Liquid State," is evidently intended to emphasize the possibilities of yielding under stress even for a so-called solid earth. It is based mainly on a paper by Darwin. This paper is given not only in the *Philosophical Transactions*, to which Hayford makes reference, but also in revised form in Darwin's collected *Scientific Papers*, Vol. II, p. 459.

¹ Heiskanen, W., Die Erddimensionen nach den europäischen Gradmessungen. Veröffentlichung des finnischen geodätischen Institutes, No. 6. Helsinki, 1926.

Über die Erddimensionen, Vierteljahrsschrift der Astronomischen Gesellschaft, 61 Jahrgang, 3tes u. 4tes, Heft, p. 215.

One correction to the third paragraph of Hayford's paper should be noticed, though it does not particularly affect the point he is making. Darwin's *revised* calculation² does not make the maximum stress-difference constant over the entire surface of the earth. The stress difference at the surface is constant over two polar caps 35° in radius. Over the rest of the earth's surface the maximum stress-difference is given by a mathematical expression different from that applicable to the polar regions and increases from the edge of the caps to the equator.

In the next to last paragraph Hayford refers incidentally to the compressibility of the earth. In this connection the reader who may be tempted to see what Darwin has to say on this point should be warned that Section 10 of Darwin's paper (pp. 497-500 of Vol. II of the *Scientific Papers* or pp. 215 of the *Philosophical Transactions*³) has been superseded. The stresses in a large *gravitating*, compressible and elastic body require a more elaborate treatment than Darwin gives. In a compressible body of the size of the earth there are secondary gravitational effects due to changes in density that must be taken account of in any adequate treatment of the problem. (See Love, *Some Problems in Geodynamics*, Cambridge, England, pp. 11-12 and 89-90, 1911.) This necessary revision of Darwin's argument does not affect the first part of his paper, upon which Hayford's statements are based.

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IT IS NOT NECESSARY TO PLACE GEODETIC ARCS IN VARIOUS LATITUDES.

This paper is an attempt to bring an idea, to which greatly exaggerated importance has been attached, into its proper relation to other ideas.

² This section of Darwin's paper is revised in the Proceedings of the Royal Society, Vol. 38, 322, 1885, and the revised form is incorporated in the text of the collected *Scientific Papers*. There are, however, several fairly obvious typographic errors in this part of the *Scientific Papers*. A factor a is lacking in both of the right-hand sides of equations (39) p. 479, Vol. II, and a factor e in the right-hand sides of the second and third of the subsequent expressions for Δ (not numbered) that occur further down on the same page.

³ The treatment of the case of compressibility is different in the original paper and in the revised form of the *Scientific Papers*, but in neither version is the fundamental difficulty overcome.

To avoid any possible misunderstanding, I desire to emphasize the fact at the outset that this paper does not deal with determinations of the figure of the earth based upon observations of gravity and that the conclusions reached do not apply to gravity determinations.

The figure and size of the earth may be determined from triangulation and astronomic observations, that is from geodetic measurements. The determination by triangulation of the length of an arc anywhere on the earth's surface and by astronomic observations of the curvature of that arc, enables one to compute the size of the earth, provided the amount of the flattening is known.

The idea seems to prevail that in order to determine the flattening of the earth from such geodetic measurements, it is necessary to make the measurements in various latitudes. The basis for this idea is that the flattening must be determined by measuring radii of curvature of the spheroid which differ considerably from each other and that arcs of the meridian in high latitudes, near the poles, have relatively long radii of curvature and those near the equator relatively short radii. For example, according to the Clarke (1866) determination of the figure and size of the earth the radius of curvature in the meridian in latitude 72° (at the northern end of either continent) is 6,393,700 meters, and at the equator is 6,335,000 meters. The difference of these two radii is 58,700 meters. Now if one geodetic arc of the meridian is measured in latitude 72° and another at the equator and the difference of the two radii of curvature is found to be much less than 58,700 meters, it indicates that Clarke's value of the flattening, $\frac{1}{295}$, is too great, or vice versa, and the appropriate correction to Clarke's, value may be computed.

This is the usual reasoning which leads to the conclusion that it is very important to have geodetic measurements in various latitudes.

This reasoning is seriously defective in that the attention is unnecessarily confined to arcs of the meridian. Since the introduction of the telegraphic method of determining differences of longitude, there has been no good reason for excluding arcs of the parallel from such reasoning. Let us include them.

The flattening may be determined by measuring the difference of the radii of curvature of two arcs in any one latitude, one an arc of the meridian and the other an arc of the parallel.

The measurement of the latter determines the radius of curvature of the spheroid in the prime vertical plane. Thus in the central part of the United States in latitude 39° the meridian radius is 6,360,600, and the prime vertical radius is 6,386,800, and their difference is 26,200. This difference is large enough to secure a good determination of the flattening by observations in this one latitude.

The prime vertical radius is, in all parts of the United States, much longer than the meridian radius. The meridian radius varies in the United States (according to Clarke, 1866) from 6,347,400, in latitude 26° in southern Florida and Texas, to 6,371,800, in latitude 49° , on the Canadian border, a range of only 24,400 meters, not so great as the difference between the meridian and prime vertical radii in latitude 39° . The prime vertical radius varies in the United States from 6,382,400, in latitude 26° , to 6,390,500, in latitude 49° , a range of only 8,100. But if measures are made in the United States of both the meridian and the prime vertical radii, there is available the total range of difference from the short meridian radius, in southern Florida and Texas, to the long prime vertical radius on the Canadian border, from 6,347,400 to 6,390,500, a total range of 43,100. This total range is nearly twice as great as is available from arcs of the meridian alone in the United States, and is nearly three-fourths as great as is available from arcs of the meridian alone scattered from the equator to latitude 72° .

Bearing in mind, then, that the strength of the grip obtained upon the flattening is greater the greater the range of radii of curvature of the geodetic arcs measured, it is evident from these figures, first, that it is more important to emphasize that both the prime vertical and the meridian radii should be measured than to insist upon measurements in various latitudes, and, second, that by measuring both arcs of the parallel and arcs of the meridian within the limits of the United States, almost as good a grip may be obtained upon the flattening as from meridian arcs alone scattered over the whole world.

It may be urged that this presentation is biased and incomplete in that it fails to suggest that one should not only utilize the difference between the prime vertical and meridian radii of curvature but should also still further strengthen the grip upon the flattening by utilizing as large a range of latitude as possible for both these radii. If the range of latitude is extended

outside the United States, southward to the equator, advantage may be taken of the decrease in the meridian radius to 6,335,000, and if extended northward to latitude 72° advantage may be taken of the increase in prime vertical radius to 6,397,800, making a total available range of 62,800, which is only 46 per cent greater than the total range available within the limits of the United States. This is a gain well worth securing, but, nevertheless, it is a minor gain. For the fact remains that more than two-thirds of the available range of radii to be secured between latitudes 72° north and latitude 72° south is available within the limits of the continuous continental portion of the United States.

In contrast to this minor gain let me remind you that triangulation can be done at a much smaller cost in a home country than in a distant equatorial region or in the ice and snow of a high latitude, that the strength of a figure of the earth determination depends largely on the number of astronomic observations utilized, that the strength of the grip obtained upon the figure and size of the earth increases very rapidly as the size of the areas covered by the triangulation concerned is increased, and that, other things being equal, one triangulation covering an area of a certain size gives a grip much stronger than two or more separate triangulations covering in the aggregate the same area.

These and other considerations indicate that progress is to be made in determining the flattening of the earth from geodetic measures by securing large continuous areas of triangulation well supplied with astronomic observations, these areas to be in the most convenient localities, rather than by securing arcs scattered through a large range in latitude.

To secure a large range in latitude in geodetic observations is of some importance. It is of much more importance that certain other conditions, which are but hinted at in this paper, shall be fulfilled by the observations.

THE ELLIPTICITY OF THE EARTH IS NOT A PROOF OF A FORMER LIQUID STATE.

The idea is often expressed, even by physicists in good standing, that the observed ellipticity of the earth is a proof of a former liquid state. I am here to challenge this idea. The challenge is not new, nor are the ideas I shall express new. But the frequency with which this mistaken idea is repeated

shows that it should be challenged again, and in a direct and positive manner.

This idea is, I believe, based upon a gross underestimate of the magnitude of the stress-differences which would be produced within the earth by any departure of the actual ellipticity from that corresponding to the rate of rotation of the earth on its axis.

Sir George Darwin has incidentally computed these stress-differences in connection with his classic paper entitled, "On the Stresses Caused in the Interior of the Earth by the Weight of Continents and Mountains."⁴ He finds that if the present ellipticity differs from the ellipticity due to present rotation by one-eighth part, the stress-differences due to this cause which necessarily exist in the earth are one-half ton per square inch over the whole surface of the earth, are as a rule greater the greater is the depth below the surface, and are four tons per square inch at the center of the earth.

The statement that the stress-difference is four tons per square inch at a given point within the earth means that, at that point, the compressive stress is four tons to the square inch greater in the direction of maximum compressive stress at that point, than it is at that point in the direction of minimum compressive stress. A stress difference of four tons per square inch corresponds in its effect to a compressive stress of four tons per square inch applied to two faces of a cube in a testing machine while the other four faces of the cube are left free from pressure.

Would the earth, even if it were solid throughout, stand the stress-differences, from one-half to four tons per square inch, without permanent deformation, or would it yield gradually to them and acquire a new shape, a new ellipticity, corresponding more nearly to that due to the rotation?

Four tons per square inch is the breaking stress-difference of a good granite, according to Darwin. All materials begin to suffer permanent deformation at an elastic limit considerably less than the stress-difference necessary to break them. The longer the period of application of the stresses, the farther the effective elastic limit falls below the breaking stress-difference. In the case in hand the stresses exist continuously for geologic ages. A standard authority on engineering practice gives as the safe working load for

⁴ Philosophical Transactions of the Royal Society of London, 1882, Vol. 173, pp. 187-230.

granite masonry one-fifth of a ton per square inch, and states that this is about the maximum in existing structures. This engineers' safe load for granite is only 40 per cent of the stress-difference over the whole of the earth's surface and only 5 per cent of the stress difference at the earth's center as computed by Darwin for a departure of one-eighth part of the actual ellipticity from that due to rotation. It is evident, therefore, that if the earth were, throughout, a solid mass of continuous good granite it could not retain an ellipticity differing by one-eighth part from the rotation value. It would yield and change its shape.

Granite is one of the strongest of the materials found abundantly in the accessible part of the earth's crust. The heterogeneous mixture composing the earth is probably much weaker, on an average, than granite.

The materials composing the earth are, except near the surface, subjected to high temperatures which tend to reduce the strength available to resist stress-differences.

Failure, that is permanent deformations, at any point tends to concentrate further failure at and near that point. The heterogeneous mixture of materials composing the earth probably has many spots of weakness in it which tend to cause failure long before the stronger material gives way. The stress-differences at which failure commences, therefore, depend upon the strength at the exceptionally weak spots in the material rather than upon the average strength of the material.

Taking into account, first that the heterogeneous mixture composing the earth is probably weaker on an average than good granite; second, that the part of this mixture on which the stress-differences in the case under consideration are greatest, the part near the center, is subjected to high temperatures tending to reduce its strength; third, that the stresses under consideration exist for geologic ages with one sign, if there is no yielding under the stresses; and, fourth, that the effective strength is fixed by the weak spots in the material, rather than by the average material, I believe it is probable that the earth, even if solid throughout, begins to yield and assume a new shape whenever the maximum stress-difference, at the center, is as great as one-fifth ton per square inch, the safe load used by engineers for granite masonry. If this estimate is correct, the departure of the actual ellipticity from that due to rotation must always have been and is now less than 1/160 part, even if the earth has always been and is now solid throughout.

The best available value for the observed ellipticity is $\frac{1}{298}$ and the denominator is not known with certainty within two units. $1/160$ part corresponds to approximately two units in the denominator. Therefore, if one deduces the strength of the earth under stress-differences from a comparison of the observed ellipticity with the computed ellipticity due to rotation, the errors of observation are such that he will not be justified in stating that the material with which he is dealing, the earth, is not solid throughout.

Moreover, if one tries to compute accurately the ellipticity due to rotation he finds himself confronted with a difficulty, namely, that the computation is affected by the assumed relation of depth and density, a relation which is not accurately known.

On the other hand, if one attempts to prove the closeness of agreement of the actual ellipticity with the ellipticity due to present rotation, by studying the distribution of land masses, by showing that there is neither an appreciable equatorial protuberance nor an appreciable polar protuberance of land above the water, he will find himself facing the fact that $1/160$ part of the ellipticity corresponds to a protuberance of only 130 meters, too small to be detected with certainty.

If possible compressibility of the material composing the earth is taken into account, the conclusions of this paper are strengthened.

The evidence afforded by the observed ellipticity of the earth is not sufficient to prove that the strength of the material in the interior of the earth, available to resist stress-differences, is now, or ever has been, so small as to justify the statement that said material is now, or ever has been, a liquid.

FOSSIL ZONES IN THE COLORADO SHALE OF ALBERTA.

P. S. WARREN AND R. L. RUTHERFORD.

INTRODUCTION.

The Colorado shale, or beds of equivalent age, underlies the greater portion of the province of Alberta. Over a considerable part of the area it is known only from the records of deep wells on account of the thick accumulation of overlying beds. In the foothills area the Colorado is exposed in several belts, due to the folding or faulting resulting from the orogenic activity in the mountain area immediately to the west. In northern Alberta beds of equivalent age are exposed on the Athabaska and Peace rivers where the strata are nearly flat-lying. It is with the development of the Colorado shale in the foothills belt that this paper will largely deal.

On account of the great thickness of the Colorado shale and the faulting and folding so common in the foothill structure, it has become increasingly necessary to determine some definite horizons in the formation for the purpose of dealing with detailed structure and correlations within this area. Broad divisions of the Colorado strata have been defined on the basis of lithology, but it has been found necessary to use other means to delimit smaller divisions. After considerable investigations in different parts of the foothills it has been determined that fossil zones can be established to considerable advantage. It is the intention in this paper to define these zones in so far as they have been investigated.

Most of the collections have been made and their stratigraphical relationships noted by the junior author; the identifications and correlations have been the work of the senior author. The fossil lists given below have been published in part in reports of the Scientific and Industrial Research Council of Alberta. The information contained herein is based on observations made in the foothills from the Crowsnest pass north to the Athabaska river.

LITHOLOGICAL CHARACTER AND DIVISIONS OF THE COLORADO SHALE.

The Colorado has been recognized by most workers in the foothills as a series of shales of marine deposition lying

between two series of fresh-water deposits. These shales have been frequently designated as the "Benton" but it is now known that these marine beds in the Alberta foothills are more inclusive than correct usage of the formational term "Benton" implies.

Attempts have been made to divide the Colorado into formations or members on a lithological basis. Cairnes,¹ in 1905, was one of the first to attempt this division, but more recent work has shown that his divisions were incorrectly correlated even within the Moose Mountain area.

The lithological divisions of the Colorado are better defined in the western part of the foothills belt and especially in the west central part of Alberta, where Malloch² first recognized three lithological divisions. He assigned the names *Blackstone* shale, *Bighorn* sandstone, and *Wapiabi* shale to these divisions in the Bighorn coal basin, which is situated north of North Saskatchewan river.

The Blackstone shale is the lowest formation and consists of a thick series of dark-colored marine shales, which are thin-bedded and fissile. Calcareous beds, usually less than one foot thick, occur within the formation, but on the whole it is remarkably homogeneous in character.

The Bighorn sandstone overlies the Blackstone shale and consists essentially of fine-grained sandstone, shaly sandstones, and bands of conglomeratic sandstones. Occasional carbonaceous beds approaching coal seams have been observed.

The Wapiabi shale overlies the Bighorn sandstone and consists of a thick series of dark-colored marine shales. In many respects these are similar to the Blackstone shales but the Wapiabi beds frequently carry ironstone nodules through several hundred feet of vertical sections. Such nodules are notably absent in the Blackstone.

Malloch's divisions have been found to extend throughout the foothills between the North Saskatchewan and Athabaska rivers. The Blackstone and Wapiabi shales persist laterally without any marked change in lithology. The Bighorn sandstone, however, shows a thinning from west to east across the foothills from about 400 feet in the more westerly occurrences to about 250 feet in the districts to the east.

The lithological divisions of the Colorado are not indicated

¹ Cairnes, D. D., Moose Mountain District, Geol. Surv., Can., Mem. 61, 1914.

² Malloch, G. S., Geol. Surv., Can., Mem. 9E, 1911.

on most maps of different parts of the foothills of southwestern Alberta, although the presence of arenaceous beds within the formation has been noted by most investigators. Cairnes³ observed sandstone beds within the shale series exposed along the Bow river. He named these the Cardium sandstone and assigned the shales above them to the Claggett, which is of Montana age. It has been shown recently* that these upper shales are largely also of Colorado age.

The Cardium beds are well exposed along the Bow river below the mouth of the Kananaskis, where they have a thickness of about 150 feet. The lithological character is similar to that of the Bighorn and shows a similar thinning from west to east across the foothills.

The Cardium and Bighorn are correlated tentatively until the foothill area between the Bow and North Saskatchewan has been more thoroughly examined. This correlation is strengthened by the fact that the Wapiabi shales lying above the Bighorn sandstone in west central Alberta are represented by an almost equal thickness of similar beds in the foothills along the Bow river. These shales have an average thickness of 2,000 to 2,300 feet.

South of the Bow river district it is more difficult to divide the Colorado lithologically, since there is evidence of a thinning of sandstone members of the Cardium in that direction, where this formation appears to be represented by several arenaceous beds separated by appreciable thicknesses of marine shales. Such conditions prevail in the foothills along the Elbow and Sheep rivers.

Farther south in the Crowsnest pass district the arenaceous beds apparently are not represented in the Colorado exposed in the outer foothills, and in the inner foothills to the west they are very thin.

Summarily, the lower Colorado throughout the foothills may be said to consist of a series of dark-colored, fissile shales of homogeneous character. The thickness on the average is estimated to be from 1,000 to 1,500 feet. It has been impossible to get a definite thickness for this division at any locality, since in all places a certain amount of duplication of strata by folding and faulting has occurred. Arenaceous beds usually occur above these lower shales and show a thickening from east to west and also from south to north, parallel to the foothills.

³ Op. cit.

* Rutherford, R. L., Sci. & Ind. Res. Coun., Alta., Rept. No. 17, 1927.

The upper Colorado beds are also dark-colored shales, but on the whole somewhat more arenaceous than the lower beds, less fissile, and frequently characterized by nodules.

FOSSIL ZONES.

Barren zone. The lower 200 to 500 feet of the Colorado shale is nearly barren of recognizable fossils. Fish scales, including *Ichthyodectes* sp., have been collected in considerable abundance, especially near the base of the formation. *Inoceramus corpulentus* McLearn sometimes occurs in nodules in this zone and a specimen of *Prionotropis woolgari* Mantell has been collected. Neither of these fossils, however, is characteristic of this horizon and both occur more abundantly in higher beds.

Inoceramus labiatus zone. About the middle of the Blackstone or lower Colorado shale, *Inoceramus labiatus* Schlothheim occurs very abundantly. The zone extends from 500 to 800 feet through the section, but the exact limits of the occurrence of this fossil are not definitely known and considerable variation may be expected in different areas. It has never been found to extend as high in the section as the Bighorn, or Cardium, sandstone. On the Elbow river *Inoceramus labiatus* occurs in beds about 200 feet above the base of the formation. The only other fossils found in this zone are new species of *Inocerami*.

Prionotropis zone. In the uppermost beds of the Blackstone shale *Prionotropis woolgari* Mantell and *P. hyatti* Stanton? occur, but never very abundantly. The zone of *Prionotropis* is quite restricted, as this fossil so far has not been found in or above the Cardium or the Bighorn sandstone in the foothill region nor associated with *Inoceramus labiatus* below. As mentioned above, it seems to occur very sparingly below the *Inoceramus labiatus* zone. It is possible that different species may be represented at the different horizons. It is interesting to note that McLearn also finds *Prionotropis* occurring at two horizons on the Smoky river in northern Alberta.⁵

Bighorn sandstone. The Bighorn or Cardium sandstone is not considered to represent a true fossil zone; nevertheless it is often abundantly fossiliferous. Most of the fossils occurring at this horizon have a considerable vertical distribution.

⁵ McLearn, F. H., Geol. Surv., Can., Bull. No. 42, p. 119.

The outstanding fossil in this sandstone is *Cardium pauperculum* Meek and its prevalence gave rise to the name of the member in southern Alberta. The species also occurs at a higher horizon. The total fauna collected from the Bighorn and Cardium sandstones is as follows: *Cardium pauperculum* Meek, *Inoceramus pontoni* McLearn, *Inoceramus coulthardi* McLearn?, *Inoceramus fragilis* H. & M.?, *Inoceramus corpulentus* McLearn, *Inoceramus* sp. nov., *Pinna*, sp. undet., *Anomia subquadrata* Stanton, *Turritella?* sp. undet.

Scaphites zone. The *Scaphites* zone is probably the most fossiliferous horizon in the Colorado shale in the foothills and is also the most easily recognized zone. As a rule *Scaphites* appears just above the Cardium sandstone and has a long, vertical range throughout the Wapiabi or upper Colorado shale. It has been found within 300 feet of the top of the formation, but the most prolific horizon is in the lower part. The fossils generally occur quite well preserved in ironstone nodules, but casts and poorly preserved specimens are sometimes found in the shale itself, especially in the upper part. The fauna, other than new species from this horizon, contains these forms: *Inoceramus umbonatus* M. & H.?, *Inoceramus* cf. *corpulentus* McLearn, *Cardium pauperculum* Meek, *Oxytoma nebrascana* (E. & S.), *Ostrea congesta* Conrad., *Anomia subquadrata* Stanton, *Baculites asper* Morton, *Scaphites ventricosus* M. & H., *Scaphites ventricosus* var. *stantoni* Reeside, *Scaphites ventricosus* var. *interjectus* Reeside, *Scaphites ventricosus* var. *depressus* Reeside, *Scaphites vermiformis* M. & H., *Scaphites vermiformis* var.

Baculites ovatus zone. The uppermost fossiliferous horizon in the Colorado shale has been designated the *Baculites ovatus* zone, after the most abundant fossil present. It is recognized that *Baculites ovatus* Say has a long, vertical range in marine Montana beds above this horizon, but in the foothills of Alberta this is apparently the highest marine horizon in the section, so the name is considered appropriate for this region. The *Baculites ovatus* zone occurs in the uppermost 200 to 300 feet of the Colorado shale and in places this marine fauna has been found in the lowermost beds of the overlying sandstones. The significance of this zone in determining structure may be appreciated in the shattered strata of the foothills region in places where the sandstone beds overlying the Colorado shale bear a strong lithological resemblance to the underlying sandstones. The following species have been collected from this horizon:

Inoceramus sp. nov., *Oxytoma nebrascana* (E. & S.), *Cardium pauperculum* Meek?, *Pholadomya papyracea* M. & H., *Tancredia americana* M. & H., *Callista?* sp. undet., *Tellina?* sp. undet., *Ostrea congesta* Conrad, *Ostrea* sp. nov., *Baculites ovatus* Say, *Baculites ovatus* var. *harsi* Reeside, *Baculites aquilaensis* var. *separatus* Reeside, *Scaphites leei* Reeside, *Desmoscaphites bassleri* Reeside?

CORRELATION.

Recently Dr. J. B. Reeside, of the United States Geological Survey, has published some details relative to the zoning of the Colorado and younger formations in southern Montana, Colorado and New Mexico.⁶ It is interesting to note that most of the zones erected by Reeside in that area are about equally applicable to the Colorado shale of Alberta. It is our intention to discuss these zones separately and to mention the points of similarity or disparity in the two areas.

The Barren zone. The barren zone at the base of the Colorado shale in the foothills of Alberta has yielded so few fossils that it is not our intention at the present time to make any definite statement regarding its correlation. Further field work may produce evidence to make a correlation justifiable. Reeside mentions a zone below the *Inoceramus labiatus* horizon which contains guide fossils in the western part of the Western Interior province, but which in many places is nearly barren of fossils, especially in the northern part of that province.⁷ The guide fossils mentioned by Reeside have so far not been found in Alberta, but the nearly complete absence of fossils at this horizon may justify a tentative correlation with the lower part of the Graneros shale and the Thermopolis shale of the Western Interior states. The same evidence combined with its stratigraphic position would justify a correlation with the so-called Benton shale of Manitoba.

Inoceramus labiatus zone. This zone is included in the Greenhorn limestone of the central Great Plains region of the United States and is characteristically developed over a very wide area. It occurs in the so-called "Niobrara" of Manitoba,

⁶"A New Fauna from the Colorado Group of Southern Montana." U. S. G. S., Prof. Paper, 132-B, 1923, pp. 25 and 26, and

"Upper Cretaceous and Tertiary Formations of the San Juan Basin, Colorado and New Mexico." U. S. G. S. Prof. Paper 134, pp. 9-13.

⁷"A New Fauna from the Colorado Group of Southern Montana." U. S. G. S., Prof. Paper 132-B, p. 26, 1923.

which must not be confused with the Niobrara formation of the Great Plains region which is stratigraphically higher in the section. This is the most easily recognized horizon in the Lower Colorado shale in Alberta on account of the great abundance of specimens. McLearn reports this species as far north as Smoky river in Alberta.⁸

Prionotropis zone. Although the total fauna represented in the *Prionotropis* zone in the foothills in Alberta is extremely limited, it may, without doubt, be correlated with the Carlisle fauna of Reeside. The Carlisle shale and related horizons in the Great Plains region of the United States carry a much richer fauna, chief among which is *Scaphites warreni* Meek and Hayden. This species appears to be notably absent in Alberta and the correlation is based solely on the occurrence of the genus *Prionotropis*. This genus has been recorded by McLearn from Smoky river and has not, so far, been reported from Manitoba.

Scaphites zone. The fauna of the *Scaphites* zone is undoubtedly a Niobrara fauna. Although there is a considerable discrepancy in the total number of species as listed by Reeside from this horizon in the Great Plains region and those collected in Alberta, nevertheless many of the most prominent species are common in the two areas. Chief among these are *Scaphites vermiformis* and *Scaphites ventricosus*, which constitute the guide fossils for this horizon in Alberta. Next in importance may be mentioned *Ostrea congesta* and *Baculites asper*. The *Ostrea* is not restricted to this zone, being found also at a higher horizon, while *Baculites asper* may be proved to have a much longer time range. They occur, however, most abundantly in the *Scaphites* zone. *Inoceramus umbonatus* has not been definitely identified in our collections, but it probably occurs throughout the foothills area, as it has been listed by McLearn from the Badheart sandstone farther north on the Smoky river. McLearn reports *Scaphites ventricosus* from the same horizon.

Baculites ovatus zone. The highest zone in the Colorado shale in Alberta contains a fauna which appears to warrant a correlation with that of the Telegraph Creek formation in Montana.⁹ The correlation is based largely on the first appearance of *Baculites ovatus* and a *Scaphites* which bears a considerable resemblance to, if not absolutely identical with,

⁸ McLearn, F. H., Geol. Surv., Can., Bull. No. 42, p. 119.

⁹ U. S. G. S., Prof. Paper 134, p. 11.

Desmoscaphites bassleri Reeside.¹⁰ The absence of *Scaphites hippocrepis* (DeKay) suggests a little lower horizon than the Eagle sandstone. The fauna from this horizon shows an intermingling of Colorado and Montana species but as it occurs above the typical Niobrara fauna, which formation is considered to be the top of the Colorado group in the central Great Plains region, it must be considered Montanan in age. There is no break in the lithology between the beds containing the Niobrara fauna and those containing the Telegraph Creek fauna in the foothills in Alberta; consequently no formational name has been applied to the beds of Montanan age in this great shale sequence. On the Smoky river in northern Alberta McLearn lists *Baculites ovatus* from the shale member of the Smoky river formation above the Badheart sandstone, which latter formation contains the Niobrara fauna. It is probable that this shale represents the same horizon as the *Baculites ovatus* zone in the foothills.

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¹⁰ Specimen identified by Dr. Reeside.

POEBROTHERIUM.

F. B. LOOMIS.

In the summer of 1927 the Amherst College Expedition, working in the Oligocene near Hat Creek, Wyoming, found a skeleton of *Poebrotherium wilsoni*. When taken from the matrix this showed so many points of difference from the classical conception of this early camel, that it seems desirable to review our knowledge of the Oligocene camels, in order to make a more accurate picture of this important form, and to distinguish more clearly the four known species.

The genus *Poebrotherium* was established by Leidy in 1847,¹ when he gave the name *P. wilsoni* to the first vertebrate specimen sent in by Mr. Alexander Culbertson from the Bad Lands of South Dakota. The type is an imperfect skull with the milk teeth still in place, but all the molars erupted. In 1881² Cope in an article on foot structure names another larger species, *P. labiatum*. Scott in 1891³ gives a detailed description of the osteology of the genus and presents the first restoration of the skeleton of the whole animal. This is based on "the larger part of a skeleton belonging to one individual," which seems to be the same material as that on which Cope based his species *P. labiatum*. It consists of the skull, the cervical vertebrae, part of the dorsal and lumbar vertebrae and the hind limb. The rest of the restoration is made by taking data from other individuals. It is from this restoration of the skeleton that the flesh restorations, so familiar to every student of vertebrate palaeontology, have been made. Certain questions were at that time left open, such as the vertebral formula, the number of the ribs and their length.

The specimen found last summer lay in the matrix fully articulated from the skull through the sacrum, and with the limbs still in articulation. It was exposed from the right side and the lower parts of the right front leg and the right hind leg were weathered away; but both of the limbs on the left side were complete as were the ribs. There are seven cervical vertebrae, 13 dorsals, and 7 lumbar. The delicate ribs

¹ Proc. Acad. Nat. Sci., Philadelphia, 3, p. 322.

² Amer. Naturalist, 15, p. 269.

³ Jour. Morphology, 5, p. 1.

were taken out by first exposing the inner side and then gluing to each a strip of cloth, so that when removed, though fractured, each was complete and its length and width were preserved beyond a doubt. An extra skull was found with the skeleton and this had an even more perfect dentition than the one articulated to the backbone.

The first striking feature of the skeleton as it lay in the rock was the high arch of the backbone, in contrast to Scott's restoration which has the back nearly flat as in the living

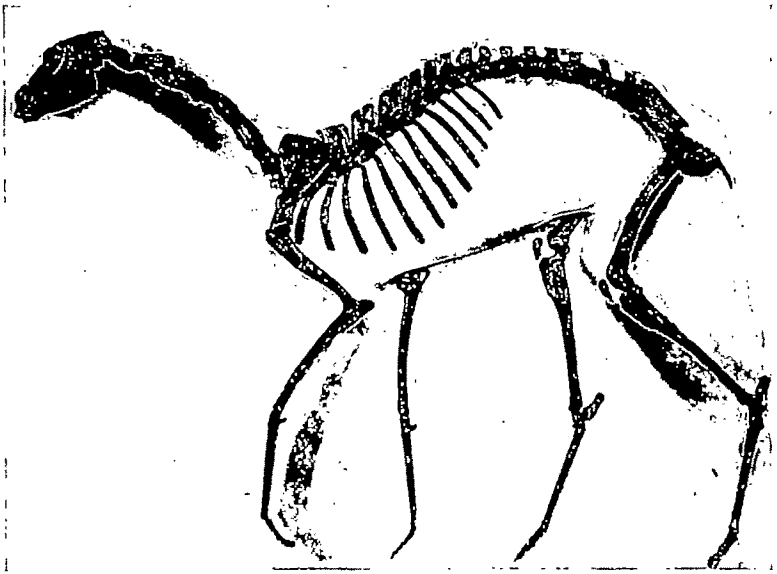


Fig. 1. The skeleton of *Poebrotherium wilsoni*. About 1/10 natural size. It measures 29½ inches high from the highest part of the back to the feet.

guanaco. Though we took the vertebrae apart and expected to make a low arched back, they would not articulate, except as the back was considerably arched. Then too in spite of having one more vertebra than in the Scott restoration the whole back is shorter than in previous restorations. Another striking feature which came out at once was that the fore limbs are short as compared with the hind limbs, which again coincides with the arched back.

Fig. 1 is a photograph of the new specimen (27-41 of the

Amherst Museum) which gives a new, and I believe more accurate, idea of *Poebrotherium*. It is an animal less like the typical modern camels such as the guanaco, and more like a gazelle in outline. Instead of walking flat-footed on a pad, I believe *Poebrotherium* (and also the Miocene genera like *Oxydactylus*, *Stenomylus*, and *Protolabis*) walked on the tips of its toes as does the deer. This is indicated by the articular surface of the metapodials not extending so far to the front as in modern camels; and by the fact that the last phalynx is not reduced, but is full sized and with sharp angles on the sides. The flat foot and straight back are later acquisitions taken on at the time the camels adapted themselves to desert life sometime in the Pliocene.

There has not been a comparative study of the species of *Poebrotherium* and there is a considerable amount of confusion in the determinations in various museums. This shows especially in the paper by Wortman on the "Extinct Camelidae of North America,"⁴ where he figures a skull *P. wilsoni*, which Hay, when making his catalogue of Fossil Vertebrates of North America, recognized as belonging to another species, and so proposed for it the name *P. eximium*. Considerably later Troxell⁵ found a very perfect skull of a *Poebrotherium* which is peculiar in having the upper canine reduced in size and the third upper incisor enlarged. To this he gave the name *P. andersoni*. Aside from the peculiarity mentioned it is similar to *P. labiatum*. This makes four species so far described.

The Amherst parties have collected *P. wilsoni* and *P. labiatum* from the same bed in eastern Wyoming, a skeleton of each and several skulls. *P. labiatum* differs in having a considerable gap between pm. 1 and pm. 2 while *P. wilsoni* has a shorter gap. *P. labiatum* is supposed to be about 10% larger. However we have found specimens of *P. labiatum* that were actually smaller than *P. wilsoni* and in no two is the interval between pm. 1 and pm. 2 the same. There is wide variation both in the spacing of these teeth and in their size. In fact the size and shape of the premolars and incisors is extremely variable. The result of looking over the Amherst material, that of the American Museum and some from other museums leads me to the conclusion that the difference between these two species is not

⁴Bul. Amer. Museum Nat. Hist., 10, 110, 1898.

⁵This Journal, 43, 381, 1917.

more than sex differentiation. *P. labiatum* seems to be the male, while *P. wilsoni* is the female, the differences being either sex, age or individual. As to *P. andersoni* it may be noted that the dentition taken to illustrate the upper teeth of *P. labiatum* has the third incisor enlarged and the canine reduced (Fig. 2 D). This is not as marked as in the type of *P. andersoni* (Fig. 2 C) but is the beginning of the same sort of thing.

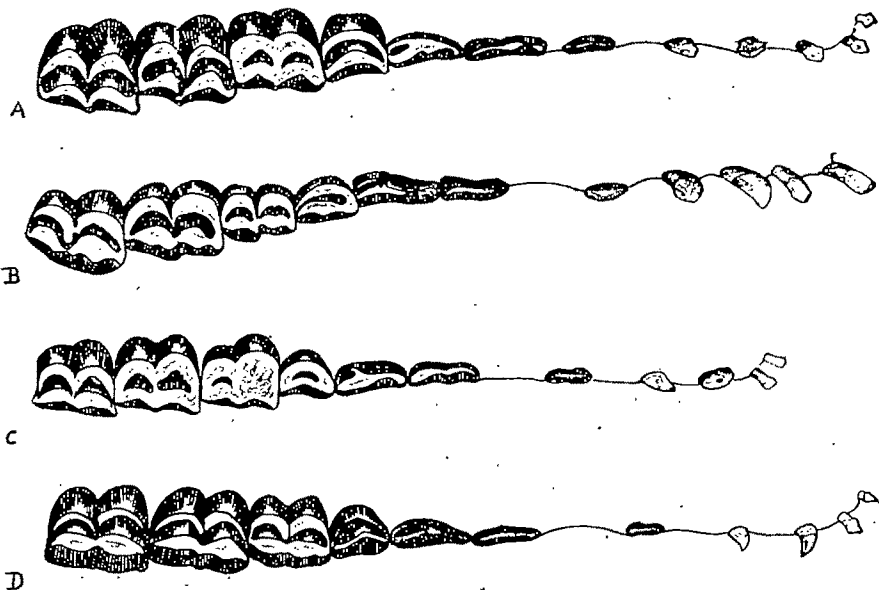


Fig. 2. The upper dentitions of the four species of *Poebrotherium*. A—*P. eximium*, B—*P. wilsoni*, C—*P. andersoni*, D—*P. labiatum*. Natural size.

The type of *P. andersoni* comes from the same beds as those in which we collected *P. wilsoni* and *P. labiatum*. In the original descriptions this species is compared mostly with *P. eximium*, but it is very close to *P. labiatum*. The type of *P. labiatum* is incomplete in the canine and incisor region, so we have no means of comparing it with the type. However, I have seen specimens of *P. labiatum* with the canine larger than the third incisor, equal in size, and with the canine much smaller than the third incisor. The type of *P. andersoni* is an extreme case in this respect but I cannot see in it anything justifying a separate species. *P. eximium* has an almost closed dentition and comes from the lowest beds of the middle Oligo-

cene and may well be regarded as a separate species. The anterior portion of the dental series in *Poebrotherium* is extremely variable and for any one of the three species (*P. wilsoni*, *P. labiatum*, and *P. andersoni*) there are specimens grading into the next species so completely as to make it impossible to draw a line between the species, and all occur in the same bed. I therefore feel that in these species and in others which could be established on equally good grounds, we are

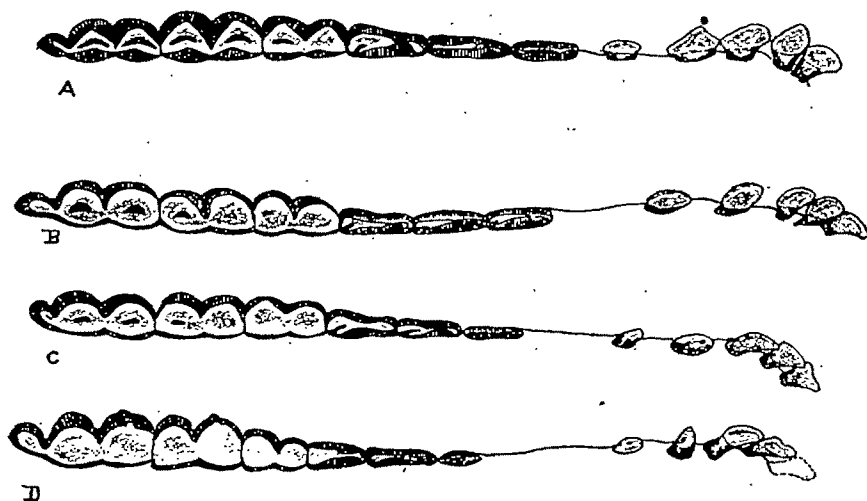


Fig. 3. Lower dentitions of the same four species in the same order.

dealing with the normal variation due to sex, age and individuality. This conclusion is confirmed by looking at a series of modern guanaco skulls. Here also is found a wide range of variation in the development of the premolar and incisor teeth. It seems to be characteristic of the family to have considerable differences in the size and spacing of these anterior teeth.

That the differences which have been used to distinguish species in *Poebrotherium* may be readily seen, I have made comparative drawings of the four species which have been described, using the types in the case of *P. eximium* and *P. andersoni*, and for the other two species the best skull available, as the types do not have the anterior portions of the skulls preserved.

Poebrotherium has been several times referred to as an abundant fossil. Though the writer has collected in the middle Oligocene parts of at least ten seasons he can by no means call it a common type of artiodactyl. By going over several collections I find that *Poebrotherium* represents about 5% of the finds of mammals; so is to be thought of as one of the rarer animals and by no means a dominant form. The occurrences are relatively abundant in the following order, *Merycoidodon* (*Oreodon*), *Mesohippus*, *Hyracodon*, *Leptomeryx* and then *Poebrotherium*. In the Miocene beds the representatives of the camel family become relatively more dominant.

AMHERST COLLEGE,
AMHERST, MASS.

A NEW ECHINOID FROM THE SUNDANCE OF WEST-CENTRAL WYOMING.

A. K. MILLER.

Fossil echinoids are comparatively rare in the Jurassic strata of North America. As far as the writer has been able to learn, only nine species, placed in six genera, have been described from them. Only one of these nine species, *Holecypus pealei* Clark, from Yellowstone National Park, Wyoming, came from the Sundance formation; the others came from the Jurassic strata of California and Texas.

The material on which the following description is based was collected from the valley of Baldwin Creek, about six and one-half miles north-west of Lander, Wyoming. The echinoids occur there in a ten-foot, light grey, thin-bedded, finely crystalline limestone member at what appears to be the base of the Sundance. This member is abundantly fossiliferous and contains, in addition to the echinoid remains, *Astarte dacotensis*, *Astarte* sp., *Trigonia* sp., shark teeth, numerous unidentifiable fragments of pelecypods, and a few fragments of gastropods. Fragments of echinoid spines are fairly numerous in the limestone, but coronal fragments are comparatively rare. Those obtained were collected largely from limestone boulders that had been quarried during the building of a culvert.

The presence of echinoid remains at this locality was first noted during the summer of 1925 by Prof. M. G. Mehl, the writer, and other members of a University of Missouri geological party. The locality was again visited by the writer during the summer of 1927, and additional material was collected.

The writer wishes to acknowledge the assistance of Prof. R. T. Jackson of Peterboro, New Hampshire, who has seen the specimens here described and who has offered valuable criticisms.

Hemicidaris sundancensis, n. sp.

This species is represented by three more or less complete coronas, one essentially complete spine, and numerous fragments of both. The preservation of the specimens is fair, but the apical disk is not preserved in any of them. The spines

and the coronas occur in very close association, indicating that they belong to the same form.

The tests of the three more or less complete specimens are depressed-spheroidal and free from distortion. They measure

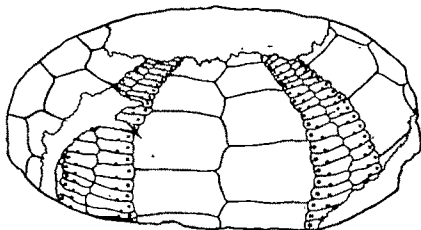


Fig. 1. *Hemicidaris sundancensis*, n. sp. Side view of the smallest of the cotypes, x 4.

about 5.5 mm., 7 mm., and 8 mm. in height and about 13.5 mm., 15.5 mm.; and 17.5 mm. respectively in diameter. The ambulacra at the mid-zone of the smallest specimen are about 2.9 mm. wide, whereas those of the largest specimen measure about 3.5 mm. in width. There are two columns of 31 low

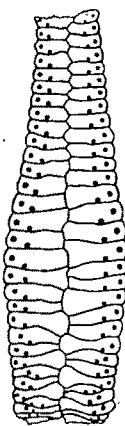


Fig. 2. *Hemicidaris sundancensis*, n. sp. Ambulacrum, x 6.

simple plates in each ambulacrum. These plates in the adoral part of the corona differ greatly in shape, as shown in Figure 2, and the pore-pairs are polyserially arranged. Every third plate seems to have enlarged and expanded at the expense of the intervening plates, and there seems to be a start toward the

development of compound plates. However, in each ambulacrum, all the plates with two exceptions, one in each column, are primaries. These two exceptions are occluded plates and occur near the peristomes (Fig. 2). Passing adapically (to the later added plates) one finds that these plates gradually become similar, and above the ambitus all are long, narrow,

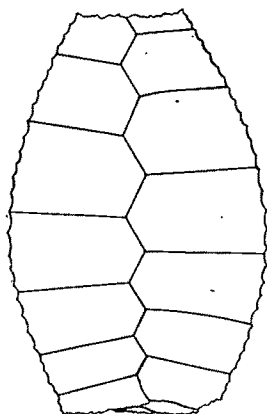


Fig. 3. *Hemicidaris sundancensis*, n. sp. Interambulacrum, $\times 6$.

pentagonal primaries with uniserial pore-pairs. Near the mid-zone of the smallest specimen these plates measure about 0.5 mm. in height, 1.5 mm. in width, and 0.3 mm. in thickness; whereas similar plates in the largest specimen are about 0.6 mm. high and 1.75 mm. wide. The pores of the pore-pairs, near the mid-zones, are about 0.35 mm. apart in the smallest specimen, and 0.5 mm. apart in the largest. Five to six ambulacral plates equal the height of an interambulacral plate near the mid-zones.



Fig. 4. *Hemicidaris sundancensis*, n. sp. Primary spine, $\times 6$.

There are two columns of eight pentagonal plates in each of the interambulacral areas. The interambulacra of the three cotypes measure about 6 mm., 6.5 mm., and 7 mm. respectively in width at the mid-zones. The interambulacral plates at the mid-zone of the smallest specimen measure about 2 mm. in

height and 3.7 mm. in width; whereas those of the largest specimen measure about 2.75 mm. in height and 3.7 mm. in width. These plates are approximately 0.5 mm. thick at the mid-zones. Each interambulacral plate is marked by a large, nearly central, perforate, primary tubercle, a large scrobicular area, and several secondary tubercles and very small miliary tubercles distributed along a narrow border outside the scrobicular area. This border is wider on the adapical sides of the plates than on the adoral sides.

The peristomes of the cotypes are large, and on one of the interambulacral plates in the basicoronal row of one specimen there is an indication of a gill incision.

The primary spines are cylindrical and taper slightly. One essentially complete spine was obtained. It measures 10 mm. in length and is approximately 0.6 mm. in diameter near the center of the shaft. The shaft, which ends bluntly, is longitudinally finely striate. There are approximately thirty striae on the nearly complete specimen. These striae extend from the blunt distal tip of the shaft to the annulus, but do not extend beyond it.

Because of the polyserial arrangement of the pore-pairs adorally, and simple plates with uniserial pore-pairs above the ambitus, and because of the large peristome and probable gill incisions in the basicoronal row of interambulacral plates, this form is doubtfully referred to the genus *Hemicidaris*.

Cotypes.—Cat. No. 3555, Paleontological Collections of the University of Missouri.

UNIVERSITY OF MISSOURI,
COLUMBIA, Mo.

THE FOUCAULT PENDULUM OF THE PEABODY MUSEUM OF YALE UNIVERSITY.

CHARLES S. HASTINGS.

INTRODUCTION.

The demonstration of the rotation of the earth by purely physical means, as devised by Foucault in 1858, has always exercised a fascination upon intelligent people. For this reason it has long been recognized as a desirable addition to museums and to physical laboratories; but the prevalent opinion that for successful action a great length of pendulum is requisite, which demands a free space possessed by few buildings, has restricted the number of examples. One of the purposes of this article is to show that the importance of this condition is overestimated; another is to prove the extraordinary attainable accuracy of the pendulum when properly designed and constructed, ranking it indeed among instruments of precision.

The principle guiding Foucault in his invention is that a pendulum, absolutely free from constraint, will maintain its plane of vibration irrespective of the rotation of its supporting member. Therefore, if suspended over a fixed horizontal table which must revolve with the earth, its plane will appear to rotate at a constant angular velocity in a determinate direction in the northern hemisphere, which is reversed south of the equator. The hourly angle of apparent revolution of the plane is $15^\circ \sin \text{Lat.}$, since the earth makes a complete rotation of 360° in twenty-four hours. The chief practical difficulties in executing the experiment are two; first, the frictional resistance of the air and of the suspension may bring the pendulum to rest too quickly, and, second, the inevitable tendency of the bob to move in a varying ellipse instead of remaining in a vertical plane. Evidently both of these defects are reduced by increase of the length and weight of the pendulum, whence the inclination to look for success only in such pendulums.

In the case under discussion great length is precluded since, although the tower of the museum is high, it has a free opening only through the second floor, so that above the table a vertical height of 35 feet only is at command. The accepted methods of suspension are in general, either the familiar gim-

bals, consisting of two knife edges at right angles such as employed in the mariner's compass, or a hook of which the point rests on a hard steel plate while the wire which carries the bob depends from the lower part of the hook. The former method has been adopted in the massive pendulum, weighing 1,300 pounds, which swings in the Palmer Physical Laboratory at Princeton University, and the latter in the famous 105 ft. pendulum at Washington. A third method, which the writer used more than forty years ago in his regular lectures on experimental physics, was by means of an elastic wire firmly clamped at the top. This was found to be far better than the elaborate knife-edge suspension supplied by the German instrument makers and which was at that time, perhaps, quite novel. This experience was taken as a guide in our design. Another departure from customary practice was the use of a far less massive bob. This was, of course, at a sacrifice of a more sustained amplitude, but it possessed a certain convenience and, as will appear below, the inevitable decrement in amplitude does not impair its value for the end in view.

DESCRIPTION OF PENDULUM.

The bob is a lenticular mass of lead weighing 28 pounds suspended by a highly elastic piano wire about 35 feet in length over a cement table. The form of a horizontal double convex lens is chosen so as to reduce the air resistance and the wire is as fine as it was thought safe to use; it breaks under a stress equivalent to twice the weight of the bob. The bob has a pointer below at its center. Upon the table rests a circle of paper, its center being vertically under the point of suspension and having a plate of glass lying upon it to keep it in place. The first and third quadrants are divided by diameters spaced 9.9° apart and numbered with the hours of the clock commencing with IX when the pendulum is released every morning. The radius of the circle is 11 inches, which is the amplitude of the swing when starting. The table bears an octagonal lantern $53\frac{1}{2}$ inches across and 32 in height which serves to protect the pendulum from air currents; this is an essential precaution because its locality is just inside the main entrance doors. The release is accomplished by the ordinary method of burning a thread which initially fixes the bob at the edge of the disk.

When this pendulum was first mounted it was found that the path of the pendulum changed slowly from an apparent straight line to a very elongated ellipse with an increasing excentricity. This fault seems practically characteristic of all such systems. The defect would not be very objectionable since the direction of the major axis of the ellipse is determinable with almost as great accuracy as rectilinear oscillations, were it not for the fact that such elliptic paths carry with them also a variation in the azimuth of the path which contradicts the assumed law of rotations. The causes of this troublesome defect are various. Any variation in the moment of inertia of the oscillating system with respect to axes in different directions; minute differences in position of knife-edge suspension or even of different degrees of sharpness; or, in case of hook suspension, departure from a true surface of revolution in the point of the hook. In our own case the cause is demonstrably due to different degrees of stiffness of the wire in different directions. The difference may be due to minute lack of roundness or to strain in its structure. The fact that when unconstrained the wire lies in a coil seven or eight inches in diameter inclines me to the latter explanation. To eliminate it we may seek a better wire, or, which is far from impossible, compensate by a proper change in effective diameter at the upper portion of the wire, neither of which methods have we followed. It is easy to describe what the general effect of such disturbances would be although a rigid solution of the problem may be troublesome on account of the large number of constants involved. For example, if the pendulum were subject to the elasticity of the wire alone it would swing with an enormously long period and in a path which may be described as a Lissajous figure of a false unison; as it is, we must think of this modification impressed upon the simple pendulum motion with the important restriction that, since the wire is revolving with the earth as is the table below, the whole change has a period of about eighteen hours during which it completes all of its phases since the wire makes a half revolution in that time. It is this property of our system which led us to a far simpler adjustment. The top suspension was first turned so that the growth of ellipticity was thought to be the greatest attainable; it chanced that the circulation in this ellipse was left-handed as seen from above, indicating that the initial release was in the quadrant following the plane of minimum rigidity. Then the upper suspension was adjusted until the

growth of ellipticity in the path was thought to be equal but with a circulation in the opposite direction. Finally the upper holder was turned to a position midway between these. With this adjustment the pendulum meets all our requirements; it followed the division of the dial with a precision which shows no obvious errors for much more than the eight hours during which the Museum is open to the public. The time can be read from the dial with greater precision than from a sun dial.

THE PENDULUM AS AN INSTRUMENT OF PRECISION.

The instrument is so satisfactory and repeats so exactly its performance day after day that we were prompted to test its ultimate capacity. To this end Mr. Herpich and his assistant made for me a series of observations by a very simple method. A sheet of cardboard with a centered circle of 22 inches diameter was placed upon the table and over this was laid a thin wire straightened by a bow. At nine o'clock, when the pendulum was released, and at every successive hour until four o'clock in the afternoon, the wire was adjusted so as to lie as accurately as possible in the plane of oscillation as determined by the pointer at the bottom of the bob, and the points where the wire crossed the circle were marked with a pencil. This process was repeated on four different days so that we secured a total of 64 such points. From these cards the angles of rotation of the table for each interval were found from the measured chords, thus eliminating errors of excentricity. The accuracy of the records proved highly satisfactory as appears below in the final analysis.

The mean values of the rotation angles are given in the first column of the table below under the heading θ , and the dif-

θ	h	δ	H	v
°	°	°	°	°
5.00	9.875	+0.074	9.949	+0.018
14.79	9.816	0.119	9.935	+0.004
24.50	9.774	0.161	9.935	+0.004
34.12	9.718	0.198	9.916	—0.015
43.68	9.692	0.228	9.920	—0.011
53.27	9.674	0.254	9.928	—0.003
62.87	9.663	0.272	9.935	+0.004
			9.931	± 0.002

ferences in the next column, under h , are the successive hourly angles of rotation. The latter angles are subject to accidental

errors of observation and to periodic errors due to the imperfection of the wire. Assuming the latter to follow the law

$$\delta = a \sin (\theta + \alpha)$$

we have to find such values of a and of α as will make the sum of the apparent errors, under v , equal to zero and the sum of their squares a minimum. This process yields $\alpha = 0^\circ.284$, $a = 10^\circ$, whence we conclude that the rotation per hour of a horizontal plane at the latitude of the pendulum is $9^\circ.931 \pm .002$. To reduce this to sidereal time by which we measure the rotation of the earth, it is necessary to multiply by the ratio of 23 hours and 56 minutes to 24 hours, which reduction gives $H_0 = 9^\circ.903 \pm .002$ for the required hourly rotation.

Perhaps the readiest way to give a definite idea of the accuracy of our measurement is to deduce from it the latitude of the pendulum. This is derived from the equation, given above,

$$\sin \text{Lat.} = H_0 / 15^\circ$$

whence $\text{Lat.} = 41^\circ.312 \pm .016$; the true latitude, as measured directly from the Yale Observatory, is $41^\circ.311$. Thus the final conclusion is that the pendulum has determined the latitude with an error of only 0.4 of a statute mile with an expectation of an error not more than twice as great. This is far more accurate than ordinary sextant determinations at sea, and it could obviously be improved by better, readily devised methods of measuring.

CONCLUSION.

The sharp distinction between mean solar time and sidereal time so plainly betrayed by the pendulum suggests some interesting reflections as to how far our accumulation of knowledge derived from astronomical observations might be obtained were we cut off entirely from such observations—in short, how far the physicist with his methods could replace the astronomer and his older science. Suppose, for example, that the earth were surrounded by a layer of clouds, as are probably all the other planets with a single exception, so that no celestial body could be observed, then by means of such pendulums the physicists could prove that we were living on the surface of a rotating globe having a determined period. Moreover, they could fix accurately the position of the equator and of the latitude of any accessible place; by measurements

between two determined latitudes the size; and, in view of the lengthening of the degrees at higher latitudes, even the spheroidal shape of the earth would reveal themselves. By observing the intervals and durations of successive periods of light and darkness, aided by photometry, the length of the solar year in terms of the period of the earth's revolution could be determined accurately in a very few years. Such careful photometric observations would be certain to fix the apparent orbit of the external source of light including its declination and excentricity; the data attaching to the sun would be confirmed by analysis of the tides and the inevitable discovery of the existence of the moon, with the approximate constants of its orbit, would follow such analysis.

In closing this description of our pendulum and its capacities it gives me pleasure to record our obligations to Mr. F. C. Herpich, the mechanician of the Museum, for his sustained and highly effective interest in the experiment.

YALE UNIVERSITY,
NEW HAVEN, CONN.

A LATE PALEOZOIC POSITIVE AREA IN NEVADA.*

T. B. NOLAN.

In order to correlate formations found in the Gold Hill quadrangle, Utah, the writer recently reviewed the available information on Paleozoic sedimentary rocks in the northern Great Basin and adjacent regions. Reliable sections are, unfortunately, few in number and rather widely scattered areally. These few, however, show rather well defined trends in the lateral variations in thickness and lithology of the sediments of the various Paleozoic periods, and show moreover that such trends in the pre-Carboniferous portion of the section are notably different from those in the Carboniferous. The writer believes that this difference indicates the existence of a positive axis or geanticline in western Nevada during the later Paleozoic.

Twelve of the sections may be grouped together to form a fairly representative east-west cross-section of Paleozoic formations in the belt included between the 38th and 41st parallels. The standard of accuracy of these probably varies considerably. Some, like Eureka, Nevada, represent work done many years ago,—others, like that in the San Antonio Range, are based upon more recent reconnaissance work,—and others, such as the Tintic district, are the result of detailed mapping. Although future work may require revisions of portions of some sections, they are thought to be adequate for the very generalized deductions of the present paper. Two other detailed sections are included within this belt, but will not be considered in the text. The Pioche¹ section resembles quite closely that at Gold Hill both in thickness and in the periods represented. The Frisco² section is difficult to correlate closely because of the very few fossiliferous horizons found there.

The locations of the twelve sections in the east-west belt are shown on Fig. 1. The gaps between many of them are regrettably large. That between Nos. 3 and 4, however, seems unavoidable, because of the apparent complete covering of the

* Published by permission of the Director, U. S. Geological Survey.

¹ Westgate, L. G., and Knopf, A., *Geology of Pioche, Nevada, and vicinity*. Bull. Am. Inst. Min. Eng., No. 1647-I, 1927.

² Butler, B. S., *Geology and Ore Deposits of the San Francisco and adjacent Districts, Utah*, U. S. Geological Survey, Prof. Paper 80, 1913.

Paleozoic sediments by younger rocks. Several of the sections (Nos. 1, 4, 5, 9, and 11) are the result of as yet unpublished work by members of the United States Geological Survey. The writer wishes to express his gratitude to Messrs. Diller, Ferguson, Cathcart, and Gilluly for the use of

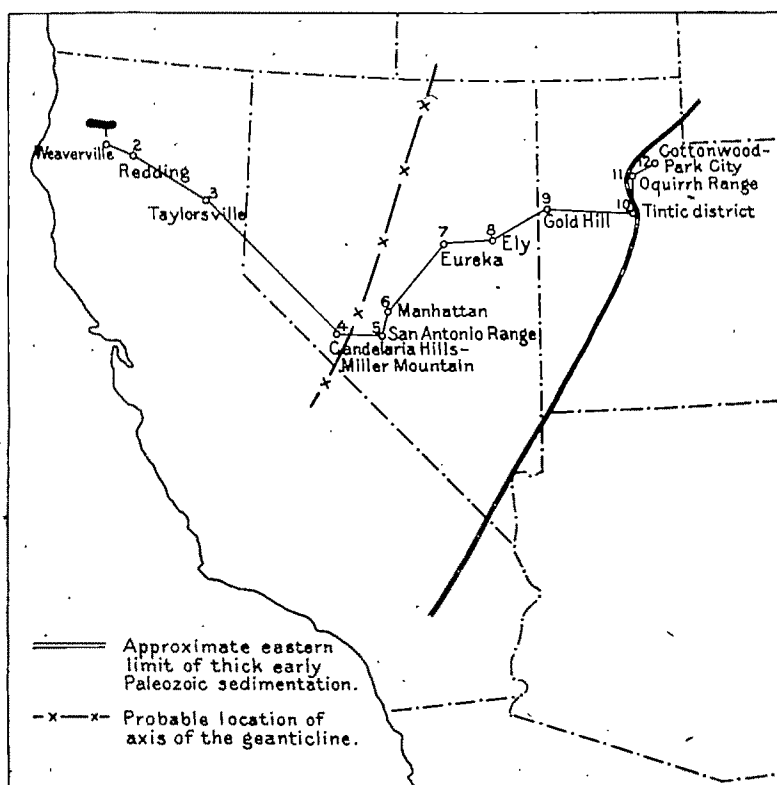


Fig. 1. Index map of the southwestern United States showing location of sections represented in Figs. 2 and 3.

these sections; to F. C. Calkins for information as to the approximate position of the contact between lower and upper Mississippian in the Cottonwood district; and to acknowledge his indebtedness to Messrs. Ferguson, Loughlin, Gilluly, Hewett, and C. P. Ross of the Geological Survey for many suggestions and criticisms.

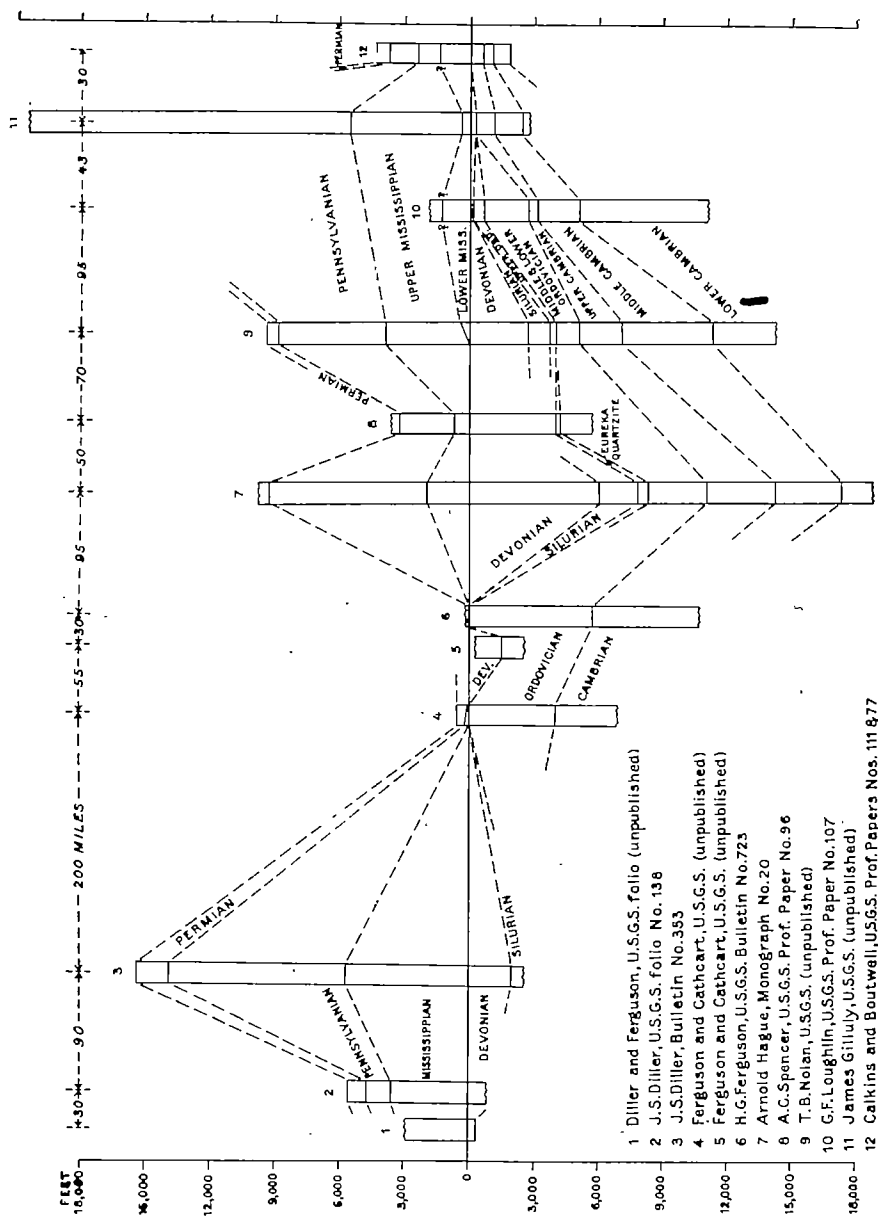


Fig. 2. Sections of Paleozoic formations in parts of Utah, Nevada, and California.

The variations in thickness of these sections are shown in Fig. 2. The heavy horizontal line in the figure represents the base of the Carboniferous. The data in the figure will be somewhat amplified in the succeeding paragraphs and will then be followed by the writer's interpretations.

1. *Pre-Carboniferous formations.*—As may be seen, there is a notable and rather regular increase in thickness of the pre-Carboniferous formations from the Cottonwood-Park City district westward to Eureka, Nevada. There seems to be little doubt that this in large part represents increased sedimentation westward, since sediments of each period are thicker when followed in that direction. Various unconformities found at Gold Hill, Tintic, and in the Oquirrh Range, show that there have been several stages during which there has been more or less erosion, but these are believed to be of comparatively small importance and were probably caused by oscillations in level of the area eastward from the Oquirrh Range. This area, whose western limit is marked roughly by the double line in Fig. 1, appears to have been strongly positive during pre-Carboniferous Paleozoic time.

The Cambrian sections are all, except for No. 12, incomplete, but nevertheless thicken westward as far as Eureka, Nevada. The thickness of Middle Cambrian at Gold Hill as compared with Eureka may be in part due to mistaken location of the boundary between it and the Upper Cambrian, as fossils are lacking at Gold Hill for some distance both above and below the horizon chosen. The small thickness of Upper Cambrian in the Tintic district is almost certainly the result of pre-Ordovician erosion. Ordovician formations also thicken westward with the maximum exposed thickness at Manhattan. The local thinning at Gold Hill is explained by erosion of pre-Upper Ordovician (pre-Richmond) age, which was in this area pronounced. The location of the place of maximum sedimentation in the Cambrian and Ordovician is unknown since only partial exposures are found in the Nevada districts studied. Although the Ordovician section at Manhattan is thicker than others to the east, the clastic nature of the sediments here and at the two nearby localities (Nos. 4 and 5) indicates that the shoreline was fairly near.

The Silurian and Devonian found at the California localities (Nos. 1, 2, and 3) show that the western shore of the geosyncline was moved to the west during these times. Whether or not the California deposits are continuous with those to the

east is, of course, unknown, but it is strongly suggested; first, by the Weaverville section, in which the small thickness of Devonian resting upon pre-Cambrian (?) shows that the sea transgressed westward, and second, by the Devonian limestone in the San Antonio Range, Nevada (section No. 5) which may be considered as a connecting link between these and the more extensive exposures to the east. Schuchert's later maps³ of the Devonian based on evidence then available show the Californian Devonian connected with the main Cordilleran sea, but his extension westward to the Pacific does not seem justified by the hitherto unpublished Weaverville section.

2. *Carboniferous formations.*—The variations in thickness of the Carboniferous portion of the section are altogether different. From a moderate thickness in the Cottonwood-Park City district, the thicknesses increase rapidly westward to the Oquirrh Range, in which Gilluly reports a minimum thickness of 15,000 feet of Pennsylvanian sandstones and limestones alone. From the Oquirrh Range westward the thicknesses decrease to Manhattan, except for the local thickening at Eureka. A considerable portion of the Eureka increase, however, seems to be caused by the presence there of terrestrial deposits. The general westward decrease is caused in part by the thinning of the deposits of the various periods, and in part by the elimination westward of the older beds. Gold Hill, for example, is at approximately the western limit of deposits of lower Mississippian age, and the upper Mississippian and Pennsylvanian disappear between Eureka and Manhattan. Farther west a small thickness of probable Pennsylvanian appears beneath the Permian in the Candelaria Hills, and a very much greater thickness of undoubted Pennsylvanian together with Mississippian at Taylorsville.⁴ At Redding,⁴ still farther west, the thickness of Carboniferous, although still moderately large, is much less than at Taylorsville.

The Carboniferous sediments of Taylorsville, Redding and Weaverville are similar lithologically to, and in part continuous with, the thick Calaveras formation of the western portion of the Sierra Nevada. They are also similar in character to the sediments in the Blue Mountains of Oregon, and strik-

³ Schuchert, C., Sites and Nature of the North American Geosynclines, Bull. Geol. Soc. Am., 34, 220, 1923.

⁴ The thicknesses of the wholly volcanic formations are not included.

ingly different from beds of the same age east of Manhattan.

3. *Carboniferous-pre-Carboniferous contact.*—One of the results of the recent mapping of the Hawthorne and Tonopah quadrangles in west-central Nevada by H. G. Ferguson and S. H. Cathcart⁵ has been to prove the presence of a marked break between Carboniferous and older Paleozoic sediments. Over most of the quadrangles Permian sandstones, locally containing beds of both conglomerate and limestone, are the only Carboniferous rocks found. In some localities these are essentially conformable in strike and dip to the older rocks; but in others angular discordances of as much as 30° in strike and 35° in dip were found. In addition, the mapping in the Candelaria Hills-Miller Mountain area showed rather broad folding in the underlying Ordovician which was truncated by the Permian beds.

The evidence outlined above indicates that in pre-Carboniferous Paleozoic time the Cordilleran geosyncline was in a broad sense a simple one, with the maximum sedimentation probably in the general vicinity of Manhattan. Shortly after the close of Devonian sedimentation, the portion which had earlier been the site of maximum deposition appears to have risen above sea-level and to have remained thus, subject to great erosion, for all of the Mississippian and Pennsylvanian time. The Permian marked the close of the elevation and planation, and slight subsidence probably permitted deposits of that period to be laid down over the entire area. It is probable that the maximum elevation occurred at or near the close of the Devonian since it is at the Devonian-lower Mississippian contact that the difference in the lateral variations in thicknesses is observed. The absence of Silurian in the San Antonio Range section, however, together with its presence in sections to the east and west, suggests that an initial rise took place near the close of the Silurian. This view is strengthened by the wide areal extent and overlapping relations exhibited by the Devonian,—the Weaverville area to the west showing Devonian upon pre-Cambrian (?) and the Oquirrh Range to the east showing Devonian (?) upon Cambrian. Elevation at this time might also have prevented later Devonian deposition locally, although, as noted above, continuity of Devonian sediments seems probable. The large proportion of clastic material in the Mississippian and in the

⁵U. S. Geol. Survey. Report in preparation.

lower part of the Pennsylvanian sequence in California and the coarse material in the upper part of the Pennsylvanian at Eureka probably indicate that elevation continued along the geanticline throughout the greater part of Mississippian and Pennsylvanian time.

The evidence afforded by structural data in the Hawthorne and Tonopah quadrangles is interpreted to mean that elevation along the geanticline was accomplished by folding or warping on so broad a scale that the angular discordance beneath the overlapping Permian is scarcely discernible. In view of the thickness of beds that were probably removed, this implies that a fairly wide area was involved. Locally, however, the elevation was accompanied by more intense folding, as in the Candelaria Hills-Miller Mountain area.

The data included in Fig. 2, supplemented by the conclusions that have been drawn from them, are combined to form Fig. 3. The upper drawing shows a cross-section of the probable sedimentation in the Cordilleran geosyncline through the Devonian, and the lower one, Carboniferous sedimentation along the same line. The two sections are generalized and take no account of the minor oscillations and warpings that undoubtedly occurred, but it is thought that they give a more graphic representation of the conditions described than the compilation of sections shown in Fig. 2.

The above discussion applies, of course, only to the relatively limited strip of territory represented by the line of section. The almost total lack of reliable stratigraphic sections of the Paleozoic in northern Nevada prevents any accurate delimitation of the trend of the positive area. The one that appears most probable is shown on Fig. 1. Near Austin, Nevada, about 75 miles north of Manhattan, Pennsylvanian limestone is reported to rest upon a large thickness of slates and limy shales of probable Ordovician age.⁶ The two, however, are stated to be conformable. Still farther north the axis seems to be located between areas of clastic rocks of Carboniferous age in the Blue Mountains of Oregon⁷ and the westward overlapping Pennsylvanian (?) conglomerates found in the Wood River region of central Idaho.⁸

⁶ Hill, J. M., Some mining districts in northeastern California and northwestern Nevada, U. S. Geol. Survey Bull. 594, 115-116, 1915.

⁷ Lindgren, W., The Gold Belt of the Blue Mountains of Oregon, U. S. Geol. Survey, 22d Ann. Report, part II, pp. 577-9.

⁸ Umpleby, J. B., Westgate, L. G., Ross, C. P., and Hewett, D. F., Geology and ore deposits of the Wood River region, Idaho, U. S. Geol. Survey Bull. (In preparation.)

The southern extension is probably less accurate. It has been drawn west of the Inyo Range⁹ because of the similarity of the section there to that of Eureka and its differences from the Carboniferous Calaveras formation in California. The thickness of upper Mississippian present in the Inyo, together

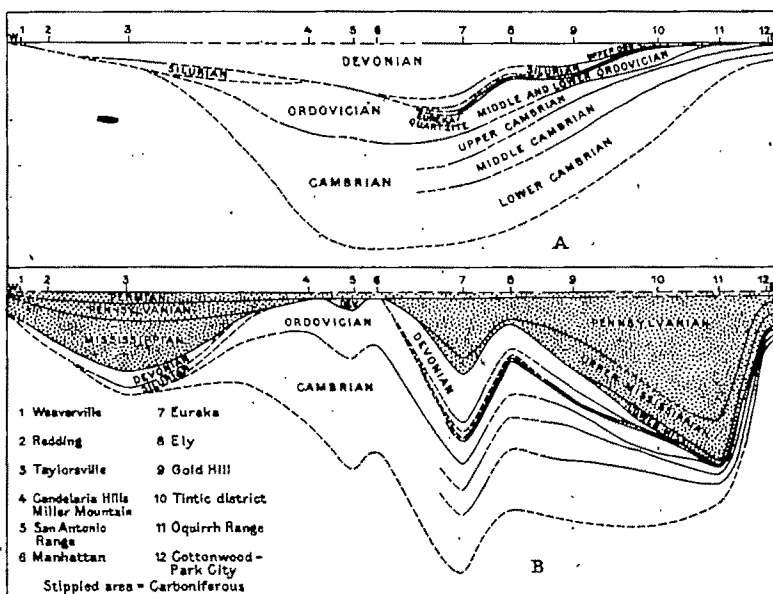


Fig. 3. Generalized cross sections through the Cordilleran geosyncline. A. At the end of Devonian sedimentation. B. At the end of Permian sedimentation.

with the thickness of the Pennsylvanian, suggests that the uplift to the south was of much smaller proportions than in the latitude of the section.

Ball¹⁰ has noted the absence of Devonian in southwestern Nevada and has suggested that this area was above sea level during Devonian and Mississippian time. It may be that the axis should be drawn more to the east in order to pass through this region, but the relationships of the Inyo Carboniferous section noted above seem to favor the position shown in Fig.

⁹ Kirk, Edwin, A geologic reconnaissance of the Inyo Range; U. S. Geol. Survey Prof. Paper 110, 19-48, 1918.

¹⁰ Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, 29, 1907.

1. This course, moreover, probably follows the approximate zone of maximum sedimentation in the lower Paleozoic, and exhibits a rather close parallelism with the eastern limit of thick sedimentation during this time.

This paper is offered with some hesitancy because of the rather meager reliable evidence upon which it is based, and mention of many contingent speculations that can not be even tentatively answered at present has purposely been omitted. The validity, however, of the main thesis—the formation in western Nevada during late Devonian time of a positive area, which existed throughout the greater part of Carboniferous time and which resulted in the breaking up of the simple early Paleozoic geosyncline into two Carboniferous seaways—is believed to be sufficiently demonstrated to merit publication.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

DISCUSSION AND COMMUNICATIONS.

GLACIAL CLIMATE IN NON-GLACIATED REGIONS.

During the Pleistocene the continental ice pushed down from Sweden into North Germany and the united glaciers of the Alps formed a piedmont glacier at the northern foot of these mountains. Beleagured between these walls of ice, central Germany must have had an unusual and probably disagreeable climate. A reconstruction of this "periglacial" climate has been attempted in a brilliant essay by the late Dr. Paul Kessler, professor in the University of Tübingen.¹

American geologists and geographers have long been concerned with the effects of the climate of the glacial period in non-glaciated regions. The work of Gilbert and his successors on the extinct lakes of the Basin and Range Province, of Huntington, and others on terraces and similar evidences of climatic changes in Asia and America, has drawn attention to the effect in arid regions of supposed world-wide changes in climate coincident with the advance and retreat of the great ice sheets of Pleistocene time. It is refreshing and stimulating, therefore, to take up a paper concerned with the climate of an area adjacent to the ice at its maximum extent.

In addition to his own observations mostly in Thuringia, Kessler has reviewed the enormous literature on pseudo-moraines, "Gehängeschutt," and "Schutterassen," which have for so long been a geological puzzle. For some time there has been a growing feeling in Germany that many of these phenomena can be explained by intense frost action. The thorough work of the Swedish geologist, Bertil Högbom, on erosive processes in the Arctic, particularly on the process of solifluction or earth flow, has had a large influence. The visit of a number of German geologists to Spitzbergen during the Eleventh International Geological Congress led to papers explaining the "Felsenmeere" of Germany as due to frost action in the ice age. Kessler has brought all this material together to show that during the ice age the rocks were riven by frost action, large quantities of angular and unweathered material were accumulated on slopes or as talus heaps, and this material was moved down hill by earth flow, producing distorted and jumbled masses, many of which were once considered moraines and evidence of the presence of glacial ice. He also shows that such distorted masses are so interbedded with soil and so related to the stream terraces of the region that multiple glaciation must be postulated.

If such phenomena characterized the region, the climate during

¹ Kessler, Paul, *Das Eiszeitliche Klima und seine geologischen Wirkungen im nicht vereisten gebiet.* 210 pp., 21 figs., Stuttgart, 1925.

the glacial epochs must have been similar to that now prevailing in Spitzbergen. He analyzes the probable distribution of the winds which, near the surface, must have moved outward from the anti-cyclone on the Scandinavian ice cap, and at higher levels must have been controlled by the prevailing westerly air drift. The ordinary winds of the time were controlled by the first of these causes and came from the northeast. They were dry and they were overlain at no great height by moisture-bearing southwest winds from which torrential rains sometimes fell. The snow-line increased in elevation from 3,000 feet on the west to 5,000 feet on the east. Shallow basins were carved on the northeast side of the hills above the snow-line, mostly by the process of nivation. The mean annual temperature, judging by the present climate of Spitzbergen and Greenland, was below freezing, but the summer months averaged above freezing and temperatures as high as 40 or 45 degrees may have existed for a few hours. The summer weather was more disagreeable than that of the winter, for the sky was doubtless almost continually cloudy and storms of snow and sleet were frequent.

In such a climate and living on a tundra vegetation, the reindeer, woolly rhinoceros and the mammoth seem to have been at home. Their bones are found at a number of places associated with the distorted masses produced by solifluction. The biologic evidence seems to confirm the characterization of the climate based on physical phenomena.

From the American standpoint the importance of this paper is greater than the interest which such a vivid picture of one of the episodes of earth history would naturally excite. The complete realization that continental glaciation implies that a zone of periglacial climate borders the ice should lead to interesting and fruitful studies of the zone immediately south of our extensive glacial boundary and particularly of the Driftless Area. That Arctic climates, or climates very similar to present Arctic climates, have prevailed in this zone at each time of glacial advance, seems indubitable. That such a climate may leave traces in the form of pseudo-moraines, flow earths (the "warp"), block-trains and even in specialized topographic forms has not been appreciated. A new attack with new criteria seems possible.

The extensive and unbroken plains which lay to the south of the ice in interior United States allowed a free sweep of winds from the southwest and may have limited the zone of periglacial climate to a very narrow strip. However, the Driftless Area, partially or completely enclosed by ice, should have been entirely subject to an Arctic climate. Similarly the influence of the ice on the climate should have been large on the Columbia Plateau enclosed between the glacier-clad Cascades and the almost continuous ice cap which overlay southern British Columbia and the Northern Rockies.

When, however, Kessler invokes the intense frost action of the periglacial climate to explain the land forms developed on sandstone in the Saxon-Bohemian Alps (Quadersandstein) and in the Vosges and the Schwarzwald (Buntsandstein) he is somewhat less convincing. One cannot fail to call to mind that the attempt to explain these forms as due to the erosive action of wind in a post-glacial arid climate has been rather vigorously resisted. Close students of the areas such as Hettner, Häberle and Novák hold that these forms are due to processes now in action operating on porous sandstone. This question must, of course, be settled by a new appeal to the field facts, but the similarity of the erosion forms of porous sandstone in all kinds of climates leads one to question specialized origins for the forms of any one district.

Kessler accepts a glacial anticyclone as a necessary part of the regime of a continental ice sheet, a viewpoint shared by many European glacialogists. However, Hörner in his description of the sand plains of Brattforsheden (Sveriges Geol. Undersök. Ser. C. vol. 20, 1926, English summary, pp. 201-203), points out that the form and position of dunes formed near the ice front, both in Sweden and in Germany, indicate that the glacial anticyclone, if it existed, did not control wind direction in front of the ice.

The concluding pages of the Kessler's essay are concerned with the proof of multiple glaciation, a live issue in Germany, where not only are there those who still believe in a single glaciation, but where even such a well-known man as Passarge holds out for only two ice advances:

KIRK BRYAN.

GEOLOGICAL MUSEUM,
HARVARD UNIVERSITY,
CAMBRIDGE, MASS.

ON AN AMMONITE SHELL INVESTING COMMENSAL BRYOZOA.

Among some Cretaceous fossils recently presented by Mr. E. R. Barton to Yale Peabody Museum, there are two specimens of the ammonite, *Sphenodiscus lenticularis mississippiensis* Hyatt, with encrusting bryozoa imprisoned between successive volutions of their deeply involute shells. The circumstance seems to be unusual enough to merit a brief notice.

The shells in question come from a bed near the top of the Ripley formation (late Upper Cretaceous) about 3 miles south of New Albany, Mississippi. They were blasted from unweathered bedrock and, although each is fragmentary, the shell substance is well preserved and the broken condition only serves the better to show the relations of the enveloped bryozoa.

The smaller specimen, about 10 cm. in diameter, includes only the inner whorls, from which the outer have been freshly but

incompletely broken away. The other specimen is a piece of an outer volution of a large shell freshly broken away from the penultimate whorl. It is possible that both specimens are fragments of one shell. In the first specimen the bryozoan adheres to the shell as it grew, its upper surface being exposed. It is partly covered on one side, however, by a portion of the dorsal wall and parts of the septa of the next volution which still adhere to it. In the second specimen the bryozoan adheres to the impressed dorsum of the outer volution, its base having parted from the inner volution on which it grew.

The bryozoan is a cheilostome apparently of the type of *Cheilopora*, forming extended thin encrusting growths and showing a tendency to have the zooaria arranged in quincunx. Since the enveloping wall of the cephalopod shell was secreted directly against the upper surface of the mollusoid the details of the latter are either covered or broken so that exact identification will be difficult if not impossible. The area of the bryozoan growth on the smaller specimen is not less than 8 square inches and it extends over parts of both sides of the shell. The fragment of the growth preserved on the inner surface of the larger specimen measures $2\frac{1}{4}$ by $2\frac{1}{2}$ inches.

As no other cases of the investment of attached organisms by cephalopods has come to my attention, it seems probable that the circumstance is not a common one. Moribund shells are, of course, frequently overgrown by encrusting organisms before burial and cephalopod shells of this sort with attached oysters, bryozoa or worm tubes are not rare; but in such shells the encrusting organisms are found only on the surface of the outer volution, or within the living chamber. Apparently the shell of the living animal, at least of the coiled cephalopods, was normally kept free of commensals. In his Notes on Living Nautilus, Dean states that in every case observed the shell was "brilliantly clean."¹ This is to be expected of active, free swimming animals whose movements would be hindered by extraneous commensals, and particularly of deeply involute cephalopods, whose earlier volutions were progressively enveloped by the later ones. Foreign objects, attached to the shell and later overgrown, must have been an irritation to the advancing mantle if not a permanent danger point of infection and decay between volutions of the shell.

Since *Sphenodiscus* is one of the last of the ammonites and one showing apparent degeneracy in the simplification of its septa, the question naturally arises whether the overgrowth of the living shell by commensal organisms may not spring from the sluggish habits of a degenerate.

CARL O. DUNBAR.

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YALE UNIVERSITY,
NEW HAVEN, CONN.

¹ American Naturalist, 35, 826, 1901.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Pyroxylin Enamels and Lacquers, by SAMUEL P. WILSON. Second Edition. Pp. xv, 253; 15 figs. New York, 1927 (D. Van Nostrand Co., \$3.50).—This useful handbook deals with the preparation and properties of the pyroxylin and their application specifically in the manufacture of enamels and lacquers. The extraordinary growth of this industry, as the result of the successful use of the nitrocelluloses in hard lacquer finishes for automobiles, has been clearly brought out. The influence of chemistry on this industry is interestingly shown in the chapters dealing with solvents and plasticisers. Organic compounds having desirable physical properties for these purposes, but hitherto impracticable for commercial use because of their prohibitive cost, are now finding extensive application because new and economical syntheses have been effected by chemical research. Considerable space is devoted to discussion of the ingredients, such as gums, resins, dyes, and pigments, which are combined with the pyroxylin in the manufacture of enamels and lacquers. Some formulas for the latter are given and also methods of manufacture and application.

The book is written in an interesting and readable fashion, and contains considerable valuable information.

A. J. HILL.

A New Source of Vitamine D.—For those who dislike cod liver oil, orange juice, or even sunshine, vitamine D can still be obtained. An English drug firm has discovered an organic compound, ergosterol, which on exposure to ultra-violet light actually produces vitamine D. The irradiated substance is now extensively on the market (in England) under the trade name of "radiostol," and is said to have an agreeable, sweetish taste not unlike chocolate. This is a discovery of no little importance, for as almost every reader will recall, vitamine D is the great preventer of rickets in children. Now, in the midst of a London fog, with no ultra-violet machine at hand, one may just feed the baby a "radiostol" pill and stop worrying.

English physicians, who have a great deal of rickets to combat because of the rather sunless climate, claim this method of administering the desired vitamine is superior to the ultra-violet ray exposure, because it is far more convenient and more readily controlled. It is hoped that rickets will be virtually eliminated by its use. A. M. SAMUEL, *Industrial and Engineering Chemistry* 20, p. 53, 1928.

E. B. KELSEY.

The Molecular Weight of Hemocyanin.—Chemists have long realized that many compounds found in living organisms, such as proteins and the like, are extremely complex, but molecular weight determinations have been very unreliable or quite impossible to carry out. Quite lately, however, by a process of ultra centrifuging, apparently reliable data for these huge molecules can be obtained. This method depends roughly on the observation that when dilute solutions of very large molecules are centrifuged at high velocities of rotation, there is a concentration of the dissolved material away from the center of rotation. The boundary can be photographically determined because of the absorption of different wave lengths of light by solvent and the concentrated solution, and the molecular weight of the dissolved material calculated on this basis.

The compound investigated by SVEDBERG and CHIRNOAGA was the physiologically important hemocyanin, a coloring pigment in the blood of many lower animals, and which is rather closely analogous to the red pigment in the blood of higher animals. Some 600 snails were martyrs to science in this case.

The average of a number of closely checking determinations gives the rather startling value of 5,000,000 [$\pm 5\%$ error] for the molecular weight of this substance. By means of other experimental data, Svedberg and Chirnoaga are able to calculate the size of these molecules and find that they enter the limits of visibility of *metallic* particles in the ultramicroscope. But organic compounds of this same size cannot be seen as they are too transparent to reflect sufficient light. *Jour. Amer. Chem. Soc.* 50, p. 1399, 1928.

Element Number 91.—No. 91 in the periodic table of elements is already occupied by two disintegration products of radio-active elements, namely uranium X_2 and uranium Z, but the extremely short life of these two elements has precluded the possibility of their actual isolation in quantity and the study of their properties. It has been recognized that a third element of atomic number 91, analogous to tantalum, should exist. V. GROSSE has succeeded in isolating the oxide of this element, which he terms *Protactinium* (Pa), in a pure state.

The source of the element was a material containing (among other things) zirconium, hafnium, titanium, tantalum, columbium, with silica and phosphate. A detailed description of the various fusions and fractional crystallizations required to isolate the element would be tedious. It is worthy of note that the oxide of this element (Pa_2O_5) is distinctly basic, a fact which aided greatly in its separation from the acidic constituents of the mineral under treatment. The life half-period of the element has been estimated at about 20,000 years. It seems that space 91 may now be considered quite permanently filled. *Berichte*, 61 B, p. 233, 1928.

E. B. KELSEY.

The Chemical Effects of Alpha Particles and Electrons, by SAMUEL C. LIND. American Chemical Society Monograph No. 2. Second Edition. Pp. 251, 13 figs. (The Chemical Catalogue Co., \$5.00.)—In advances of recent years the knowledge of the chemical effects of corpuscular radiation have followed each other so rapidly that the first edition of this monograph, which appeared in 1921, has long been in need of revision. This revision has now been made and the new volume brings the subject up to date in a most satisfactory manner. The changes have been mainly those attendant on the expansion of the text; seven new chapters have been written and much new material has been added to the existing ones. The most important of these additions are: new data on ion clustering; an up-to-date discussion of the mechanism of reaction in ionized gases, including an account of the recent work on the influence of ions of foreign and inert gases on such reactions; the use of the general equation of Mund for calculating the gaseous ionization produced by radon in spherical reaction chambers; a detailed study of the more important radio-chemical reactions which have been investigated. Some material has, however, been eliminated. A discussion of isotopes no longer is necessary since the publication of Aston's book, and the general radiation hypothesis of chemical action has been subject to so much alteration recently that it cannot be intelligently and adequately presented in this work.

In revising the text, certain changes in the organization have been made, which, in the reviewer's opinion, seem undesirable. Chief among these is the treatment of references. References to publications of Professor Lind are gathered in a special appendix while all other references are given at the foot of the page on which they occur; such segregation is rather annoying at times and there seems to be no real need for it.

Another oversight which may cause the reader some confusion occurs in connection with the treatment of Mund's equation. The symbols of Mund are used throughout the text while the figure which accompanies the discussion and which has obviously been carried through from the first edition, uses the same symbols in a different way. In this connection there is a tendency throughout the work to use symbols without fully explaining their meaning. For example, the M/N ratio is first used on page 83 but is not really explained until several chapters later, and as far as the reviewer could find, no explanation is ever given for the occasional use of the negative sign for this ratio.

These mechanical defects, however, do not seriously mar the excellence of the subject matter or the thoroughness and completeness with which the data have been compiled. In its present revised form the work returns to its position as a classic and will undoubtedly prove of value to all who are interested in this field.

J. B. AUSTIN.

An Optical Method of Measuring Small Vibrations.—An application of an interferometer method recently devised by H. A. THOMAS and G. W. WARREN appears to promise considerable value in the study of the mechanical vibrations of light moving systems.

In the form experimentally studied one of the reflecting surfaces, A, of the interferometer was attached to a vibrating reed while the other was held by a fixed but adjustable block. A simple optical system provided for the admission of monochromatic green light $5.461(10)^{-6}$ cm. and for the observation of the usual interference fringes. When A was at rest an increase or a decrease in the distance apart of the plates by $\frac{1}{2}\lambda$ would cause the fringes to shift by once their spacing. Suppose now the reed be set in vibration in a very small amplitude: the fringes will actually execute a harmonic vibration about the stationary position and always parallel to it, but they will no longer be apparent to the eye. If now the amplitude of the reed vibration is increased until it becomes a quarter wavelength of the light, the maximum vibratory movement of the fringes will be to the middle of the space between the stationary positions. As their velocity is slowest in these regions the persistence of vision is sufficient to cause the reappearance of the fringes there, i.e. apparently shifted by a half space. If the amplitude is still further increased the fringes will disappear again but will reappear when the amplitude is $\frac{1}{2}\lambda$, and so on. The point of disappearance was more definite than the maximum fringe intensity and its occurrence could be detected to an accuracy of one per cent of the wavelength of light used; that was in this case to $0.5(10)^{-6}$ cm.

The method was satisfactorily applied by the authors to the determination of the resonance value of a loud speaker diaphragm with various current actuations. It clearly may be readily adapted to measure the small vibrations of light systems where a reflecting surface may be obtained in any way, e.g. by sputtering, that would introduce no appreciable loading effect. *Phil. Mag.* 5, 1125, 1928.

F. E. B.

Atomstruktur und Atombindung; by J. STARK. Pp. xx, 198; 15 figs., one plate. Berlin, 1928 (Polytechnische Buchhandlung A. Seydel).—The author in this book expresses dissatisfaction with the mathematico-dogmatic atomic theories which aim only to arrive at some formula suitable for calculation. With him the chief desideratum is a theory which, after the H-atom, will give the structure and dynamics of the He-atom and that of H₂ the simplest chemical molecule. In other words, his demand is for some suggestion as to the structure and processes which shall guide experimental procedure and enable us to discover new relations. The author has accordingly here developed what he calls an empirical atomic theory, treating it in three chapters. In the first he postulates those conceptions and measurable quantities which from physical and chemical experiment permit one to derive the

ultimate elementary condition and behavior of a single atom. The second is devoted to the structure of the atoms of the chemical elements. In it starting with considerations of valence he discusses the disposition of the atom-shell of the light atoms, something of high and low optical frequency, the condition of the nucleus and radio-active transformations from considerations based on its fundamental structure. The third chapter treats the various combination of atoms in the chemical molecule and something also of the aggregation condition as interpreted from the preceding viewpoint.

The author does not lack assurance. He declares that of all atomic theories hitherto propounded the present volume not only gives the closest correlation with experiment but also furnishes the most general, the truest and the clearest description of those physical and chemical phenomena which arise immediately from the structure of the chemical atom and its ultimate constituents.

F. E. B.

The Modern Calorimeter; by WALTER P. WHITE. Pp. 194; 16 figs. New York, 1928 (Chemical Catalog Company, \$4.00).—The title of this new monograph in the American Chemical Society series conveys, inclusively, a proper idea of its contents and its aim, that is to give a unified account and discussion of a single topic, namely the measurement of heat by means of temperature changes in suitable bodies. An exclusive description, however, should note that it does not deal specifically with descriptive details of calorimeter construction, and also that the continuous flow calorimeter is omitted from consideration.

The plan of the author is to show how experimentation may be guided by an analysis of the various processes and the sources of error concerned. The major part of the work is devoted to estimates and computations concerning the attainable precision and reliability of various methods and designs of calorimetric apparatus. These criticisms and discussions are the outgrowth of the author's experience and investigation as a member of the Geophysical Laboratory Staff. The chapters are six in number. First, a brief sketch of calorimetric methods, secondly, the fundamental processes and measurements, thirdly, a systematic discussion of experimental efficiency. Chapter IV passes in review some particular methods such as the Twin Calorimeter, the Cold Calorimeter, the Adiabatic, and the Electric Method. Chapter V takes up the construction of special forms of apparatus, such, for example, as the vacuum walled calorimeter and the aneroid or unstirred calorimeter. The final chapter consists chiefly of suggestions as to design and the attainment of a prescribed precision.

It will be gathered that the main idea of the book is not so much instruction as emphasis upon the value which lies in a thorough criticism and discussion of the accuracy attainable in various installations.

F. E. B.

Sir Isaac Newton; by DAVID EUGENE SMITH, WILLIAM WALLACE CAMPBELL, ERNEST W. BROWN and others. Pp. ix, 351 with frontispiece and two plates. Baltimore, 1928 (The Williams and Wilkins Company, \$5.00).—The bicentenary of Newton's death was commemorated by a meeting at the American Museum of Natural History held under the auspices of the History of Science Society in collaboration with various learned societies and other organizations. The papers there presented are now collected in permanent and worthy form not merely as a memorial of the occasion, nor as a new set of biographical notes, but chiefly to supply the interested reader with a new evaluation of Newton's genius and his contributions to science. In all, thirteen writers have contributed to this collection, of which the most prominent essays are the following: Newton and Optics, by D. C. Miller; Gravitation and Modern Relativity Ideas, by G. D. Birkhoff; Newton's Influence upon the Development of Astrophysics, by W. W. Campbell; Newton as an Experimenter, by P. R. Heyl; Newton's Dynamics, by M. I. Pupin; Developments following from Newton's Work, by E. W. Brown; and Newton's Fluxions, by F. Cajori.

The book is full of interest not only to the student of science and philosophy but for every educated reader.

It is surprising that with the publishers' motto, *Sans Tache*, and their desire to produce a volume of surpassing typography, so many careless errors should have passed their inspection.

F. E. B.

The Elements of Industrial Engineering; by GEORGE HUGH SHEPARD. Pp. xii, 541; 46 figs. Boston, 1928 (Ginn and Company, \$4.80).—The economic importance of big scale industrial production with the accompanying factors of the management and guidance of employees has led to many and far reaching studies of the problems involved and their attempted solution. As a branch of knowledge it has penetrated the technical college and called forth various text books of which the present is an important example.

The author has developed his theme about thirteen so-called principles of management which he enumerates as follows: Higher Common Sense, Ideals, Personal Organization, Adaptation of Conditions and Work, Correct Methods, Instruction, Fair Deal, Discipline, Planning and Dispatching, Records, Standards, and Efficiency Reward.

The twenty chapters of the book elaborate and illustrate the application of these principles by many examples of factory and business experience. It contains a wealth of material certainly of value to the prospective, and presumptively useful to the active executive.

F. E. B.

GEOLOGY AND MINEROLOGY.

Chemische Geologie; by FRITZ BEHREND and GEORG BERG. Pp. 595, 60 text figures. Stuttgart, 1927 (Ferdinand Enke, M. 42.3a).—The wide borderland between chemistry and geology is thoroughly explored and described in this very notable volume. As is implied by its title, the emphasis in treatment is placed on the geologic aspects.

The book is divided into six parts, four of which were written by Berg and two by Behrend. Part I deals with the chemistry of the Earth as a whole—its crust and its interior,—with the circulation of the chemical elements during the geologic processes and with the relation between geochemistry and atomic physics. In their account of the internal constitution of the Earth the authors favor Goldschmidt's interpretation. Incidentally they make the common European mistake of crediting that brilliant geologist with being the originator of the idea that an eclogite shell of density 3.5 occurs below the visible crust. This idea, however, was first brought forward by Fermor, of the Geological Survey of India, who has built upon it a whole system of geologic dynamics.

Part II deals with the chemistry of magmas and Part III carries this subject forward by treating of the chemistry of the magmatic exhalations. Part IV describes in admirable fullness and thoroughness the processes and products of weathering. The following section describes the mode of formation of the sediments.

The final section (Part VI) discusses the chemistry of metamorphism. The processes of metamorphism are classified according to the following suggestive scheme:

- A. Autometamorphic processes
 - 1. Autometamorphism of cooling igneous rocks
 - 2. Diagenesis of sediments
 - 3. Diagenesis of secularly aging igneous rocks
- B. Allometamorphic processes without addition of substances
 - 1. Thermometamorphism
 - 2. Dynamometamorphism
 - 3. Regional metamorphism
 - 4. Diaphoresis
- C. Allometamorphic processes with addition of substances
 - 1. Injection metamorphism
 - 2. Pneumatolytic contact metamorphism
 - 3. Hydrothermal metamorphism

Among the novel features of this classification is the great extension given to the meaning of diagenesis, which for want of

a better term is here used to include devitrification, serpentinization, and saussuritization.

The authors are to be congratulated on this admirable work. The presentation is thoroughly up to date and is amply supported by references to original sources. These references are indeed one of many valuable features of the book, and for these alone the book can be specially recommended to those geologists who believe that all future advance in certain branches of geology will depend on advances in chemistry. Only the bolder outcrops of chemical lore have so far attracted the attention of geologists; and this volume will in a measure indicate how much lies in depth. As in the past so in the future, it will have to be the geologist who must utilize this information, for experience has shown that it is more difficult to make chemists geologically-minded than to make geologists chemically-minded. In its field this book has no peer.

ADOLPH KNOPF.

Geography, Geology, and Mineral Resources of Part of South-eastern Idaho; by G. R. MANSFIELD, with descriptions of Carboniferous and Triassic fossils, by G. H. Girty. U. S. Geol. Survey, Prof. Paper 152. Pp. 453, 70 pls., and 46 figs. Washington, 1927.—The *raison d'être* of this comprehensive report was the need of classifying the public lands in Idaho containing phosphate rock. The surveys for this purpose were begun in 1909 and extended over many field seasons; and the great store of physiographic, stratigraphic, structural, and economic data assembled in this report is essentially a by-product of these investigations.

The stratigraphic column comprises 46,000 feet of sedimentary rocks, ranging in age from Lower Cambrian to Recent. Of prime interest is the Phosphoria formation of Permian age, which contains the commercially valuable beds of phosphate rock. A reserve of 5,000 million long tons is estimated to occur in Idaho alone; if we add the amount occurring in adjacent parts of Utah, Wyoming, and Montana the total becomes nearly 6,000 million tons. There is little doubt that the phosphate rock is of marine sedimentary origin, but the exact conditions that determined the accumulation of this colossal quantity of phosphate are unknown. A remarkable feature of the phosphate rock is that it contains from 0.11 to 0.52 per cent of V_2O_5 and 0.08 to 0.23 per cent of Cr_2O_3 . It is suggested that the chromium content is due to cosmic dust that fell into the Permian sea during the deposition of the phosphate beds, but the absence of correlative amounts of Fe, Ni, and Co appear to negative this interesting suggestion.

At least five epochs of diastrophism are recognized: 1, the late Jurassic, or Sierra Nevada movement; 2, the Lower Cretaceous; 3, the epi-Cretaceous, or Laramide; 4, the Middle Miocene dis-

turbance; and 5, the epi-Pliocene. Of these the Laramide revolution and the epi-Pliocene movement are of major importance. The chief structural features were produced during the Laramide revolution: the strata were folded and overturned, and as a climax the great Bannock overthrust was developed. This remarkable structural feature, which has become well known largely as a result of the author's work, is 270 miles long and has a maximum horizontal displacement of 25 miles. On account of its bearing on the extent of the reserves of phosphate rock, it has been intensively studied and is amply illustrated in the report by many illuminating cross-sections. It has been folded during the post-Laramide disturbances and also dislocated by numerous normal faults.

The final chapter of this notable volume discusses the broader problems of the region, the earlier chapters being devoted essentially to an objective presentation of the facts. The problems specially considered are the Tertiary peneplanation in Idaho, the origin of the phosphate, and the building of the Northern Rockies. In discussing the last problem it is shown that during the Laramide revolution, the crust was shortened 52 per cent in this part of the Rocky Mountains, and that mountains probably as lofty as those of the present were produced. These mountains were obliterated by peneplanation and the present mountains are largely the results of the movements at the end of Pliocene time. It is concluded that the building of the northern Rocky Mountains was most probably caused by periodic contraction of the Earth.

ADOLPH KNOPF.

Cefalopodos del Jurásico Medio de Oaxaca y Guerrero; by CARLOS BURCKHARDT. Inst. Geol. Mexico, Bol. 47, 108 pp., 34 pls., 1927.—In this small but well illustrated monograph the author describes in detail 9 genera with 54 species (36 new) of ammonites found in the Middle Jurassic (middle and upper Bajocian, upper Bathonian, and Callovian) of southern Mexico. c. s.

The Stratigraphy of the Pennsylvanian System in Nebraska; by G. E. CONDRA. Nebraska Geol. Survey, Bull. 1, Second series, 291 pp., 7 pls., 38 text figs., 1927.—This small volume presents a detailed resurvey of the region long ago made classic by Meek and Hayden. Even though most of the system is represented, the sequence is less than 2,000 feet thick in Nebraska, where it consists essentially of alternating shales and limestones. The lower portion is not exposed within the state, but is described from drill cores. The exposed upper Pennsylvanian, represented by the Douglas, Shawnee, and Wabaunsee stages, although less than 650 feet thick, is divided into sixty-five named stratigraphic units, most of which have been traced not only across the outcrop area in Nebraska but far into Kansas, Missouri, and Iowa. The uniformity and persistence of many of these thin zones is remarkable.

The Nebraska Survey is to be congratulated on its policy of following the many members of the Pennsylvanian into adjacent states until their correlation is certainly established. This volume is a distinct contribution to Pennsylvanian stratigraphy in general and to that of the lower Missouri Valley in particular, and even though the mass of detail here presented is not sufficiently summarized and correlated, this will doubtless be done in another volume after the paleontologic studies have been completed.

C. S.

Geology of Mongolia. A Reconnaissance Report based on the Investigations of the years 1922-1923; by CHARLES P. BERKEY and FREDERICK K. MORRIS. (Natural History of Central Asia, vol. II.) Published for the American Museum of Natural History by G. P. Putnam's Sons, New York. Pp. xxxi, 475, 44 pls., 161 text figs., 6 maps, 1927.—This comprehensive monograph of the geology of Mongolia is a worthy companion to those other great Asiatic classics produced by Americans, "Research in China," the starting point for the present authors in discerning the wider structural conditions and stratigraphic sequence, and "Explorations in Turkestan," their guide to the desert processes making the present topography. The new volume, done in the best style and lavishly illustrated, treats of the geology of 5,000 miles of traverses (cross sections were constructed covering 3,000 miles) in central Mongolia and more especially in the Gobi Desert. The area described equals 200,000 square miles, and could not have been so covered "if it were not for a certain simplicity of geologic history."

The Gobi Desert, "which has proved to be one of the most productive geologic and paleontologic regions in the world," is 600 miles wide and 1,000 miles long, and yet shows an average depression of less than 6 feet to the mile—"a great sweeping upland country . . . where tireless winds sweep the shifting sands, which are the only mantle obscuring the rock floor beneath." Here are "the oldest human trails of the world," whereon "a Mongol guide is immensely more useful than any existing map." "We worked in surroundings of seemingly boundless desolation where only the unaccountable enthusiasm of the explorer, or the zeal of the scientific investigator, or the lure of the confirmed wanderer could have made the drudgery of those days appear to be worth what it cost. . . And now . . . all seems like an entrancing dream that slowly takes on the glamour of a golden age."

The book is in four parts: I, Introduction to the field and methods of work (pp. 1-36); II, Itinerary and studies made along the routes (37-190); III, Detailed locality studies with geologic maps (191-284); IV, Summaries and discussions (285-420); along with the bibliography consulted (421-448); and an index (449-475). The book is sold at cost (\$10).

Part IV, the most significant part of the book, is divided as follows: Chapter 17, Structural elements of the oldrock floor; 18-19, Surface features and their origin; 20, Stratigraphy of the later sediments; 21, Successive climates of Mongolia; 22, Summary of geologic history.

Probably the most striking single result is that the Gobi is underlain by a dominant series of highly deformed ancient formations. These are unconformably overlain by a "thin veneer," averaging hardly more than 10,000 feet, of continental sediments, which are folded little or not at all (but are faulted), and none of which are older than the Lower Cretaceous. This peneplain still forms major elements of the topography, and surprisingly large tracts of the old floor are entirely bare to-day. Outside of Gobi there is another and more ancient floor, "which is doubtless continuous beneath all of the sediments."

The Gobi basement is composed of at least six great groups of igneous and sedimentary rocks: (1) The Archeozoic T'ai Shan complex of Willis, consisting of gneisses, schists, and crystalline limestones saturated by intrusives. (2) The Early Proterozoic Wu T'ai system of Willis, of phyllites, schists, greenstones, and crystalline limestones. (3) The Khangai or Late Proterozoic series of graywackes, slates, jaspers, and quartzites. (4) The great Mongolian batholith of granite, probably of early Paleozoic age. (5) The late Paleozoic and mainly Permian series of marine shales, limestones, and sandstones, cut by dikes. (6) A middle Mesozoic series having below a thick continental sequence (locally up to 25,000 feet) of either conglomerates or sandstones with low-grade coals and probably of Jurassic or possibly Triassic age; and above, porphyries and surface flows, tuffs, and ashes in great variety.

"The axes of the Cenozoic mountains and lowlands agree very nearly with the strike of the folded Palaeozoic sediments and with the structure lines of the ancient schists and gneisses . . . The folding, thrusting, and faulting that have made mountains, have followed much the same directions in successive revolutions since early pre-Cambrian times, indicating an orderly constancy of control in the earth movements that . . . have welded together the continental elements that are now Asia" (p. 322).

The Paleozoic history of Mongolia is still an almost complete blank. Up to at least the close of the Mississippian, there was a land interval with erosion, since the Khangai series does not permit of other reference than to "the late pre-Cambrian." Between the Khangai series and the Mongolian Carboniferous, "deep seated igneous activity developed on perhaps the most enormous scale known anywhere in the world" (Mongolian batholith).

The known Paleozoic, now folded, consists dominantly of marine dolomitic limestone in a thick series, which "formed an

important part of the southern mass that emerged from the sea at the close of the Palaeozoic era, to become the core of the continent of Asia. Since Permian time, this portion of the continent has never been submerged" (p. 401).

In the Mesozoic era, "the continental character of central Mongolia became firmly established." The Jurassic sediments were developed as isolated continental deposits in subsiding areas adjacent to uplifted fault blocks, the destruction of which presumably furnished the rapidly accumulating material. Four orogenic periods had preceded and now came the fifth one, when "folding and faulting and extensive igneous eruptions closed the constructive period, and pre-Cretaceous erosion beveled across all these structures in making the great peneplane [= Great Unconformity] which reduced the Jurassic block-mountains . . . to a surface of low monotonous relief, . . . the floor or basement on which the later sediments were laid down" (pp. 402-3).

The Cretaceous series consists of five formations of continental origin, most of which are of Lower Cretaceous age (ca. 2,680 feet), though the youngest 500 feet with *Protoceratops* and rare mammals may be of early Upper Cretaceous time. It is the Iren Dabasu formation (180 feet), of seeming Lower Cretaceous age, that has the wonderful "dinosaur rookery" and the many kinds of dinosaurs (iguanodonts, ostrich-like types, and deinodonts). "On the whole, the evidence suggests that Mongolia in Cretaceous time was semiarid yet somewhat more rainy than the Tertiary" (p. 378).

The Cenozoic, of continental deposits, is represented by at least ten formations and characterized in the main by mammals. The Paleocene is 300 feet thick; the Eocene (800 feet) is very fossiliferous; the Oligocene, also rich in fossils, with the giant rhinoceros *Baluchitherium*, has 3,650 feet; the Miocene 1,500 feet; Pliocene 2,000 feet; Pleistocene 2,000 feet; and Recent from 0 to 2,600 feet. As was to be expected in a continental series, the record is very much broken.

Loess seems to be lacking, and that of China south of the Gobi may have been blown from Mongolia and from the Lop Nor basin on the southwest, especially if the mountain barriers between these lands and China were lower during part of the Pleistocene than they are now.

After Jurassic time came an unbroken history of simple warpings, in which elevation and subsidence were dominant, and in the course of which central Mongolia was lifted and warped into a broad basin with inland drainage. The greatest subsequent break occurs between the Cretaceous and Cenozoic, and after this break the history of the region seems to be that of a volcanic district.

We congratulate the authors on their marked success. c. s.

On a specimen of Elephas antiquus from Upnor; by the late CHARLES W. ANDREWS, and C. F. COOPER. Pp. viii, 25, 8 pls.

and frontispiece, 5 figs. London, 1928 (British Museum, Natural History).—About 1910 a party of engineers cut through a series of bones of a large elephant, while digging a trench on the banks of the Medway at Upnor, opposite the Chatham Dockyard, England. These bones, together with a large tusk, were completely destroyed. In 1913 the attention of Dr. Andrews, of the British Museum, was directed to this locality, but not until 1915 was it possible, under his direction, completely to excavate the remaining bones, which consisted of a composite fore limb, nearly complete hind limbs including the pelvis, a practically complete vertebral column, a portion of one tusk, and three molars. The skull was present but so badly weathered that it was impossible to excavate it.

This Upnor elephant is now mounted in the British Museum and is one of the largest of all known forms, standing about $12\frac{1}{2}$ feet high to the top of the shoulder blade. In spite of the absence of the skull, right fore limb, and ribs, it is the finest and most complete skeleton of *E. antiquus* so far described and is one of very high scientific value as a standard of comparison.

The Pleistocene clay beds in which the bones were found were deposited by the Medway River against a low cliff consisting of chalk with a capping of Thanet Sands.

A clear diagnosis of the minor characters is not possible, owing to the great mixture of specific characters which this Upnor specimen shows, when compared with other forms, and also due to the fact that many species of Proboscidea have been named and described on very fragmentary material. However, the major diagnostic characters, in addition to its great size, are the apparently unique upright position of the spines of the vertebral column and the unexpectedly small size of the teeth in relation to the great bulk of the body.

M. R. THORPE.

The Indiana Sand Dunes and Shore Line of the Lake Michigan Basin; by GEORGE B. CRESSEY (The Geographic Society of Chicago, Bulletin No. 8). Pp. xii, 480; plates, text figures and map in pocket. Chicago, 1928 (The University of Chicago Press, \$2.00).—The author of this attractive book summarizes previous knowledge of the history of the southern end of Lake Michigan, and adds much material that is interesting as well as original. In outlining the complicated changes of level which make up the history of the lake, he shows that the dune areas away from the immediate border of the present lake have not migrated from the present shore to their present positions, but that they were formed essentially *in situ* when the lake was more extensive than at present. He finds that the sand forming the dunes is derived from erosion of both the eastern and western shores of Lake Michigan, and that it is shifted southward by permanent currents. He discusses the mechanics of beach formation, and of

eolian action upon the dried sand. Ripple marks and eolian bedding are considered, and an interesting theory of dune origin by overtaking and accumulation of successive ripples is propounded. The volume is illustrated with forty very good photographs in addition to a number of text figures, and presents a pleasing appearance; it will be of value to all who are interested in this area, one of the most striking stretches of shore dunes in the world.

RICHARD FOSTER FLINT.

Illinois State Geological Survey, M. M. LEIGHTON, Chief.—Recent publications are as follows:

Geology and Economic Resources of the St. Peter Sandstone; by J. E. LAMAR. Pp. 175, maps, figs., and plates. Bulletin 53 (Urbana, 1928).—This paper is largely technological, discussing methods used in quarrying operations, the location and equipment of the many producing plants, methods of sampling and testing, the 97 uses to which the St. Peter sand is put, and the undeveloped deposits of potential value. These considerations are preceded, however, by a treatise on the lithology, structural features, and origin of the St. Peter. The author agrees with the conclusion reached by Dake in 1921, namely, that the sandstone is essentially marine; and he brings forward new evidence to support this view.

Press Bulletin Series No. 15, 1928: *Illinois Petroleum*. Contains the following short articles: A study of the core of the Yanaway Well No. 33 in the Siggins Pool, by J. E. LAMAR. Corrosion in the Eastern Illinois Oil Fields, by J. E. LAMAR and C. R. CLARK.

R. F. F.

Old Mother Earth; by KIRTLEY F. MATHER. Pp. xiv, 177, 61 text figs. Cambridge, 1928 (Harvard University Press. \$2.50).—"The radio," says the author in his preface, "is an exacting master. Debarred from the use of blackboard, stereopticon illustrations, or charts, the speaker must depend solely upon words to convey ideas and create mind-pictures." The exacting master found an able student in Professor Mather, who, after he had prepared and broadcasted fifteen popular lectures on general geology from Station WEEI in Boston, gathered together his material into an attractive little volume. There is no superfluous material here, and yet what is given is strikingly interesting. It should be as entertaining to the professional geologist and to the teacher as to the layman endowed with scientific curiosity. This is so chiefly because it is an object lesson in pedagogy, simple, lucid, yet presenting doctrine which is both in good standing and up-to-date. The subjects chosen range from the origin of life to the glacial features of New England. This number of selections of course cannot hope to cover the whole field, but cleverly written and well illustrated, they manage to give a pretty good general idea of what geology is all about.

RICHARD FOSTER FLINT.

Catalogo de Datos Numéricos Geográficos y Topográficos de la República Mexicana. Publicacion Núm. 8. Estudios Geográficos y Climatológicos. Pp. 160; 9 pls. Tacubaya, D. F., Mexico, 1927.—During the past thirty years, the Geodetic Commission, and later the Bureau of Geographical and Climatological Researches of Mexico, made a number of geodetic surveys of first order and lower grades of accuracy in different parts of Mexico for the control of mapping operations and for geographic studies.

One of the most important arcs of triangulation included in these surveys is one which follows approximately along the ninety-eighth meridian from latitude 16° N. to the Rio Grande at a point near its mouth. In 1916, by a coöperative agreement between the two countries involved, this arc was connected with the southern end of the ninety-eighth meridian arc in the United States, and this made it possible to carry the United States Standard Datum (later called North American Datum) into Mexico and thus to base the geodetic control of both countries on a single geodetic datum.

The present publication contains the geographic coördinates and other data for this important Mexican arc. It also contains similar data for several other pieces of triangulation in that country, notably in Yucatan, Lower California and the Federal District. It should be remarked that the triangulation of Lower California, as well as that along the ninety-eighth meridian, has been connected with the triangulation of the United States and that a third connection between the triangulation nets of the two countries will probably be made soon near Juarez and El Paso.

The early surveys of Mexico were in most instances detached from each other and were necessarily based on astronomic observations of positions. Due to the difficulties of the work and the lack of telegraph lines, etc., many of the first astronomic determinations were somewhat inaccurate and were based on different fundamental meridians. A very important part of the present publication is a table in which all the various astronomic stations have been carefully revised and catalogued, and referred to the Greenwich meridian.

The orthometric elevations of a large number of bench marks determined by precise leveling are given in the publication. Other geographic information of value, such as the areas of the different states and territories of Mexico and the areas of islands along the coast, are contained in the tables.

Altogether the publication furnishes a valuable addition to the geodetic and geographic knowledge of North America. The work of surveying and mapping Mexico is being pushed ahead vigorously at the present time and other publications of geodetic data will undoubtedly be forthcoming within the next few years.

C. H. SWICK.

Minerals and Mineral Substances of New Zealand; by P. G. MORGAN. Bulletin 32, Geological Survey of New Zealand, 1927. Pp. 110, 2 maps.—This is a catalogue of the minerals and mineral substances occurring in New Zealand, arranged in an alphabetical sequence. The author gives not only the localities for the occurrence of the various minerals but usually also a brief statement as to the type of occurrence and often a reference to some published description. This bulletin will be of great service to geologists and mining men in New Zealand, and it is of general interest to all mineralogists in giving accurate information as to New Zealand mineral localities.

W. E. F.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Year Book of the Public Museum of the City of Milwaukee, 1927; S. A. BARRETT, Director. Pp. 196; 178 figs. Milwaukee, June 1, 1928.—This, the seventh Year Book of the Milwaukee Museum, gives in detail the numerous additions to the collections and the new exhibits. There is also a full account of varied field activities for the year. Among the latter, the archeological work by W. C. McKern in the well-preserved Indian mounds in Sheboygan and Dodge Counties (pp. 10-30) deserves special mention; also the study of the fauna of Alaska, by O. J. Gromme (pp. 30-45); and the study of the coral reefs and the volcanic phenomena of the Hawaiian Islands by S. A. Barrett (pp. 48-80). The illustrations from photographs are excellent and add much to the interest of the topics discussed.

Abstracts of Theses. Science Series, Vol. IV. Ogden Graduate School of Science. University of Chicago, 1928. Theses submitted for the degree of Doctor of Philosophy; September 1925-June 1926. Pp. x, 440. (University of Chicago Press).—This fourth volume of the Science Series of Ph.D. theses contains abstracts of seventy-five papers distributed among the different departments as follows: Mathematics, six; Astronomy and Astrophysics, one; Physics, seven; Chemistry, nineteen; Geology and Paleontology, four; Geography, two; Botany, eleven; Zoology, six; Anatomy, two; Physiology, five; Physiological Chemistry and Pharmacology, five; Hygiene and Bacteriology, two; Economics and House Administration, five. It is a great convenience to the many interested to have these abstracts brought together in a single volume.

Physiology and Biochemistry of Bacteria. Vol. I. Growth Phases, Composition and Biophysical Chemistry of Bacteria and Their Environment; Energetics; by R. E. BUCHANAN and ELLIS I. FULMER. Pp. xi, 516, 78 figs. Baltimore, 1928 (The Williams and Wilkins Co., \$7.50).—This book is a résumé of current knowledge and theories of physiological bacteriology, a field of

study that the authors assume to include "all the applications of mathematics, physiology, chemistry, and physics to the problems of the life and growth of micro-organisms." It differs from the usual textbook that deals with the systematic aspects of microbiology—with classification, forms and types. Accordingly the new volume represents a useful supplement to such conventional compilations. There are many definitions of scientific terms and conceptions included as a convenient aid to those who need to refresh their familiarity with the physical sciences concerned with the life of bacteria. Inasmuch as the latter live and grow in a medium consisting largely of water, the writers have devoted detailed attention to the consideration of aqueous solutions, of solutes, and of the various degrees of dispersion of solutions and suspensions. Indeed, one-half of the text is devoted to the physico-chemical and physical characteristics of micro-organisms and of their environment. One-fifth of the book deals with energy relationships and their significance in bacteriology. An elaborate appendix includes references to the literature cited. Such an up-to-date summary of the newer relationships and interpretations of bacteriological phenomena should be stimulating at a time like the present when new fields of research are being developed in relation to what the authors describe as "the biophysical chemistry" of bacteria.

L. B. M.

PUBLICATIONS RECENTLY RECEIVED:

Sir Isaac Newton, 1727-1927; edited by F. E. Brasch, introduction by David E. Smith. Baltimore, 1928 (Williams & Wilkins Co., \$5.00).

Enzyklopädie der Technischen Chemie; by Prof. Dr. Fritz Ullman. 2d Edition, Vol. I. Abasin-Ausdehnung. Berlin and Vienna, 1928 (Urban & Schwarzenberg, M. 40.—, bound 48.—).

A Text-Book of Biologic Assays; by Paul S. Pittenger. Second Edition. Philadelphia, 1928 (P. Blakiston's Son & Co., \$3.00).

The Elements of Industrial Engineering; by George H. Shepard. Boston, 1928 (Ginn and Company, \$4.80).

Microtometist's Vade-Mecum; by Bolles Lee. Ninth Edition. Edit. by J. Bronte Gatenby and E. V. Cowdry. Philadelphia, 1928 (P. Blakiston's Sons & Co., \$7.50).

Grundzüge der theoretischen Logik; by D. Hilbert and W. Ackermann. Berlin, 1928 (Julius Springer, M. 7.60; bound 8.80).

Elements of Physics; by A. Wilmer Duff and Henry T. Webb. New York, 1928 (Longmans, Green & Co., \$2.20).

La Fabrication Chimique de l'Or (Procédés Jollivet Castelot). French text. France, 1928 (Chez l'Auteur, 19 Rue Saint Jean, Douai (Nord), France).

The Indiana Sand Dunes and Shore Lines of the Lake Michigan Basin; by George B. Cressey. Chicago, 1928 (University of Chicago Press, \$2.00).

Experimental Science for Junior Technical Students; by J. W. Bispham. New York, 1928 (Amer. Branch, Oxford Univ. Press, \$1.70).

A Catalogue of the Mesozoic Mammalia in the Geologic Dept. of the British Museum; by George G. Simpson. London, 1928.

Geology and Economic Resources of the St. Peter Sandstone of Illinois; by J. E. Lamar. Urbana, 1928. The State Geological Survey (No. 53).

Physical and Chemical Constants and Some Mathematical Functions; by G. W. C. Kaye and T. H. Laby. Sixth Edition. New York, 1928 (Longmans, Green & Co., \$4.75).

Early Books on Medicine, Natural Sciences and Alchemy, Third Part. Switzerland, 1928 (L'Art Ancien S.A., 7 Piazza A. Manzoni, Lugano, Switzerland).

Organic Chemistry; by J. B. Cohen. Part I, II, and III, Fifth Edition. New York, 1928 (Longmans, Green & Co., \$6.00).

How We Inherit; by Edgar Altenburg. New York, 1928 (Henry Holt, 1 Park Avenue, N. Y., \$3.00).

Intermediate Electricity and Magnetism; by R. A. Houstoun. New York, 1928 (Longmans, Green & Co., \$1.75).

The Algae of Connecticut; by Clarence J. Hylander. Hartford, 1928 (State of Connecticut Geol. and Nat'l. Hist. Survey. Bulletin No. 42).

Folklore of the Teeth; by Leo Kanner. New York, 1928. (The Macmillan Company, \$4.00).

Old Mother Earth; by Kirtley F. Mather. Cambridge, Mass., 1928 (Harvard University Press, \$2.50).

Mémoires du Service de La Carte Géologique D'Alsace et de Lorraine. No. 2; Jean Jung. Strasbourg, 1928 (Service de la Carte Géologique D'Alsace et de Lorraine).

Physiology and Chemistry of Bacteria, vol. I; by R. E. Buchanan and Ellis J. Fulmer. Baltimore, Md. (Williams and Wilkins Co., \$7.50).

The Role of Scientific Societies in the Seventeenth Century; by Martha Ornstein. Chicago, 1928 (The University of Chicago Press, \$3.00).

A Textbook of Organic Chemistry; by Joseph S. Chamberlain. Philadelphia, 1928 (P. Blakiston's Son & Co., \$4.00).

Abstracts of Theses, Science Series, Vol. IV, 1925-1926. Chicago, 1928 (University of Chicago Press).



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SEPTEMBER 1928

KANSAS PERMIAN INSECTS. PART 10. THE NEW ORDER PROTOPERLARIA: A STUDY OF THE TYPICAL GENUS *LEMMATOPHORA* SELLARDS.

R. J. TILLYARD.

[Studies aided by a grant from the Marsh Fund of the National Academy of Sciences.]

Part 9 of this series of papers (this Journal, 11, May, 1926) completed the section dealing with those orders of Insects not previously studied by Sellards, viz. the Paleodictyoptera, Odonata proper,¹ Protohymenoptera, Mecoptera, Copeognatha and Hemiptera. Part 10 now begins the study of the remaining orders, in which it is necessary to take into account the work already done by Sellards (1906-9) on the original collection of fossil insects from the same beds.

The order Protorthoptera, as defined by Handlirsch (1908, p. 128), is merely an *omnium gatherum* of primitive forms indicating the derivation of the Orthopteroid orders from an older Paleodictyopteroid stock. Handlirsch explained fairly clearly how the cockroaches (Blattoidea) might be considered as a highly specialized group derived from the Protorthoptera by way of an intermediate group, the Protoblattoidea, whose separation, however, from the Protorthoptera proper appears to be somewhat problematical; but in other directions he failed to show clearly the relationships of existing Orthopteroid orders with the supposedly parent group. Sellards contented himself with allocating the wonderful new types, which he discovered, to these Handlirschian orders interpreted in the widest sense; the result being that a large number of very diverse types were put into the Protorthoptera, making that assemblage even more heterogeneous than before, while two genera, *Purisa* Sell. and *Sindon* Sell., were allocated to the family Oryctoblattinidae within the order Protoblattoidea.

¹ Sellards, however, described a single Protodonate, *Typus permianus*, 1906, p. 249, placing it erroneously within the Odonata.

It may be said at once that the task of unravelling the lines of evolution of the various Orthopteroid orders and suborders existing at the present day is one of the greatest difficulty. Nevertheless that task must be essayed, and more especially because of the wealth of new material presented in these Permian beds of Kansas.

In describing the numerous types which he placed in the order Protorthoptera, Sellards divides them into six families, which he defines in very general terms. Most of his genera are not separately defined, but are introduced with the first species, and without any separation of generic from specific characters, no genotype being given; the venation in his drawings is not labelled, so that it is often not possible to say definitely which vein was in his mind in a given instance, and no attempt is made to indicate relationship to the numerous Protorthopteroid types described from other Paleozoic beds. These things being so, it has proved a difficult task to unravel the tangle. If I have made any errors in the determinations of Sellards' species, I can only plead that such were inevitable without a study of his actual types.

There are, in this abundant Lower Permian material, several types which, though undoubtedly Orthopteroid in the widest sense, yet stand out as very distinct from any of the types included within Handlirsch's Order Protorthoptera. The most important amongst these are the genera grouped by Sellards into the family Lemmatophoridae, in which we meet with a character never found in true Protorthoptera but only previously known in the Paleodictyoptera and Protohemiptera, viz. the presence on the sides of the pronotum of wing-like expansions of a rounded shape. This is such an extraordinary character to find in what is apparently a true Orthopteroid type, that one is impelled to study these insects with the minutest attention. Fortunately, fossils belonging to the genus *Lemmatophora* are the most abundant in the whole collection, so that there is no lack of material for all purposes. Not only are there a very large number of complete or nearly complete forewings, but well-preserved hindwings are also present, and a fair number of specimens in which portions of the head, thorax, legs and abdomen are preserved. Most important of all is the discovery of a single wonderfully preserved specimen showing practically the whole insect *Lemmatophora typica* Sell., with the forewings approximately in the position of rest, and the right hindwing accidentally projecting at right-angles to

the body and showing the venation quite clearly. (Fig. 2.) This enables fore and hindwing venations to be correlated with certainty for this genus. The perfection of preservation of this specimen, in which every tiny hair is clearly impressed on the rock, and the color pattern of both body and wings is fully preserved, makes this one of the most wonderful fossil insects ever discovered.

A study of this insect shows at once that it stands far apart from all known types of true Protorthoptera, while, on the other hand, it falls into close relationship with the recent order Perlaria or stone-flies. I propose, therefore, to take it as a type of the new order Protoperlaria, and to begin the study of the new order by a full analysis of the genus *Lemmatophora*. We shall discover from that analysis what characters may fairly be considered as of higher than generic rank, and shall be able to frame, later on, suitable definitions of the family Lemmatophoridae and the new order Protoperlaria, and to indicate their relationships with other recent and extinct forms.

Genus *Lemmatophora* Sellards.

(Figs. 1-19.)

Lemmatophora Sellards, 1909, p. 162.

Lisca Sellards, 1909, p. 163.

Sellards defines the genus as follows:

"This genus of small Lemmatophoridae has elongate membranous arched wings. The wing membrane is minutely scaly. Subcosta is not arched at the base and extends beyond the middle of the wing. Sector arises near the middle of the wing and is simple. M_1 is simple. M_2 is widely forked beyond the middle of the wing, and is thin at its origin from M_1 . Cu_1 is vaulted near its origin, and is two to three branched; Cu_2 is simple. Two to four cross-veins unite R_1 with Rs. A strong cross-vein unites Rs near its origin with M_1 ; two to four other cross-veins unite Rs with M_1 . Cu_1 is united at the arch with M_2 by two or three strong cross-veins. The anal area is traversed by two simple veins; inner angle squarose" (*sic*).

For the genus *Lisca* (l.c. p. 163) the following remarks are made to suffice:

"This is a genus of small Lemmatophoridae. The wing membrane is scaly and resembles in texture that of *Lemmatophora*. The radial sector originates not far from the middle of the

wing. It is simple and is united for a short distance with M_1 . M_2 is deeply forked. Cu_1 is forked. Cu_2 is simple. Length of front wing, $5\frac{1}{2}$ mm.; width, 2 mm."

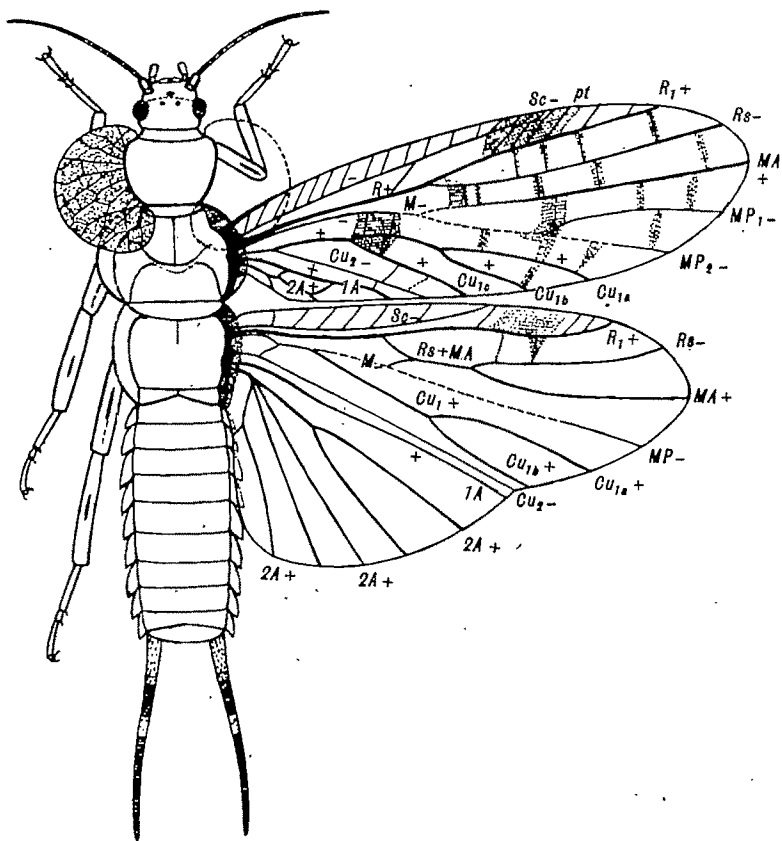


Fig. 1. *Lemmatophora typica* Sell., family Lemmatophoridae, Order Protoperlaria. Restoration of complete insect, based chiefly on Specimen No. 5115. (x 10.) Amended Comstock-Needham Notation for wing-veins:—1A, first anal; 2A, second anal; Cu_1 , first cubitus, with its branches Cu_{1a} , Cu_{1b} , Cu_{1c} ; Cu_2 , second cubitus, or *vena dividens*; M, media; MA, anterior or convex media; MP, posterior or concave media, with its branches MP_1 and MP_2 ; *pt*, pterostigma; R, radius; R_1 , main stem of radius; R_s , radial sector (unbranched); Sc, subcosta. Convex veins are marked +, concave veins —. Coloration omitted except on the left prothoracic expansion, right fore and hindwings, and the cerci.

This description includes that of the only known species, *L. minuta* Sell. No attempt is made to separate generic from specific characters. It is, however, obvious, from an analysis

of the characters of the two genera, that the only real difference between *Lisca* and *Lemmatophora* is that, in the former, Rs is fused with the anterior branch of M for a short distance, as shown in Sellards' Fig. 21 (l.c. p. 164). But, as I shall show later, a partial fusion between these veins is an occasional aberration throughout all the genera of this family, and its adoption as a generic character vitiates the whole of Sellards' system of classification. There is, therefore, no real difference between *Lisca* and *Lemmatophora*, and the former must be sunk as a synonym of the latter.

As regards Sellards' definition of the genus *Lemmatophora* itself, it is necessary to point out that he has included in it a number of characters which properly belong only to the type specimen, e.g. the position of the cross-veins and the form of the anal angle of the forewing. Actually, these vary greatly even in the type species, and must be omitted from the definition. The description of the wing membrane as "scaly" is inaccurate; even a lens of moderate power shows that it is hairy. The "thinness" (obsolescence of the chitinization of the vein) of MP (Sellards' M_2) at its origin is a family character, as is also the very typical arched formation of Cu_1 . The "thin depressed line" mentioned by Sellards in the family definition as marking off the anal area is really the true Cu_2 , while his Cu_2 is the posterior basal branch of Cu_1 , here called Cu_{1c} . The characters which actually separate the genus *Lemmatophora* from other genera of the family are the following:

Forewing.—Radial sector simple, normally separate from MA, but occasionally fused with it for a short distance in aberrant forms. Costal margin distinctly arched. Subcosta not arched basally, and extending well beyond middle of wing. MA simple. MP forked. Cu_1 with three branches, rarely two (occasionally four in aberrant forms). A complete series of costal veinlets present.

Hindwing.—Radial sector fused with MA for a space. A strong re-entrant angle or break in the contour of the posterior margin of the wing at the end of the *vena dividens* (Cu_2).

Genotype.—No genotype is given, so the first described species, *Lemmatophora typa* Sellards (l.c. p. 162) is here made the type of the genus. As there is no such word as *typa*, it must be changed either to the noun *typus* in apposition to the generic name, or else to the adjective *typica* agreeing with the generic name. The use of the termination —*a* indicates that



Fig. 2. *Lemmatophora typica* Sell. Complete specimen, No. 5115.
Photo. by W. C. Davies.

Sellards intended to use the adjective, and therefore the name is here amended to *typica*.

The generic definition given by Sellards only covered the forewing. With the abundant material now at hand, almost every part of these insects can be studied and the hindwing can be correlated with the fore.

Horizon:—Lower Permian of Kansas, U. S. A.

KEY TO THE KNOWN SPECIES OF LEMMATOPHORA.

1. Forewing with media and cubitus coalescing for a short distance. *L. anomala* Sellards.
Forewing with media and cubitus separate throughout ..2.
2. Forewing between 6 and 9 mm. in length, with Rs arising only a little before half-way *L. typica* Sellards.
Forewing between 4 and 5.5 mm. in length, with Rs arising well before half-way. 3.
3. Cu_1 in forewing three-branched (rarely four-branched in aberrant forms). *L. minuta* (Sell.).
 Cu_1 in forewing only two-branched. *L. reducta* n. sp.

Lemmatophora typica Sellards.

(Figs. 1-15.)

Lemmatophora typica Sellards, 1909, p. 162.

Lemmatophora delicosa Sellards, 1909, p. 163.

Lemmatophora hirsuta Sellards, 1909, p. 163.

Lemmatophora elongata Sellards, 1909, p. 163.

The following considerations show that the above species are synonymous:

(1) Sellards described *L. delicosa* in two lines, as follows: "This species resembles *L. typica* closely, both in size and venation. M_2 is, however, three instead of two branched."

The vein called M_2 by Sellards is the vein MP of this paper. Curiously enough, the complete specimen shown in Fig. 2 has the *right forewing* with the extra branch on MP_2 , giving the *delicosa* formation (Fig. 3), while the *left forewing* is of the normal *typica* form! This is the only wing out of the whole mass of material of this species in the Yale University Collection which shows this extra branch. *L. delicosa*, then, is merely an aberration from normal *typica*. There is another specimen, No. 5184, which has a similar extra fork on Cu_{1b} . Students familiar with the order Perlaria will recall many similar variations in the apical forking of Cu_1 , but an extra fork on either branch of M is exceedingly rare.

(2) Concerning *L. hirsuta*, Sellards says:—"The costal border of the front wing is thickly set with short backwardly projecting spines or hairs. In other respects the venation so far as can be made out agrees with that of the type species of the genus *Lemmatophora*." Now, in a number of specimens in the Yale University Collection in which both obverse and reverse are preserved, it is found that the *reverse* is normal *typica* while the *obverse* is the form *hirsuta* described by Sellards as above. This peculiar occurrence will be fully explained when dealing with the chaetotaxy of the wing. In the meantime, it is sufficient to note that *L. hirsuta* Sell. is merely a synonym of *L. typica* Sell.

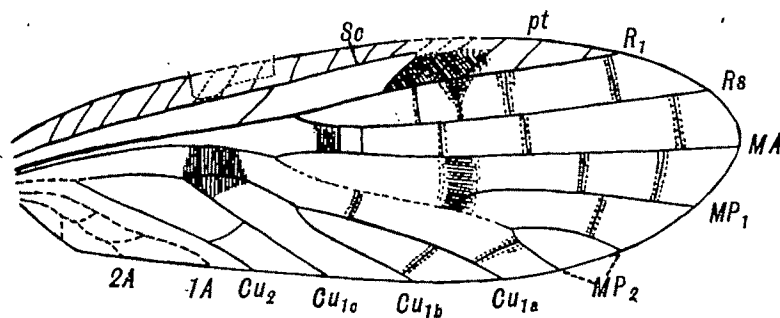


Fig. 3. *Lemmatophora typica* Sell. Venational variation *delicosa* Sell., showing extra fork on MP_2 (drawn from right forewing of Specimen No. 5115). Lettering as in Fig. 1.

(3) As regards *L. elongata*, the matter is a little more difficult. Of this supposed species, Sellards says: "This species has a more slender and "a longer front wing than that of *L. typica*. Length of front wing, 9 mm.; width, $2\frac{3}{4}$ mm."

Now the above description is quite insufficient for the diagnosis of a new species, and could only have any value if it proved definitely that the ratio of length to breadth in *L. elongata* was definitely greater than in *L. typica*. I have given below the measurements of the lengths and breadths of all the complete forewings of *L. typica* in the Yale University Collection, and have calculated their ratios. The lengths vary from 6.2 to 8.9 mm., so that the length 9 mm. given for *L. elongata* is just at the maximum for *L. typica*. The breadths vary from 1.9 to 3.1 mm., so that the breadth $2\frac{3}{4}$ mm. given for *L. elongata* lies well within the series of measurements for

L. typica. The ratios for *L. typica* (length to breadth) range from 2.8 to 3.4; the calculated ratio for Sellards' type of *L. elongata* is 3.3. This lies within the range of ratios for *L. typica*.

Consequently there is nothing whatever in Sellards' description which distinguishes *L. elongata* from *L. typica*, and it appears highly probable that the former name must sink as a synonym. An examination of Sellards' type should, however, be made, in order to find out whether there may not be other important differences which he has omitted from his description.

The detailed description of *L. typica* which here follows is based upon Specimen No. 5115 (Figs. 1, 2) with a number of details supplied from other material to supplement points which are not clear in the most complete example.

Measurements of Specimen No. 5115:—Total length of body, excluding cerci, 7.2 mm.; cerci 2.8 mm.; width across prothoracic expansions 3 mm.; length of forewing 7.2 mm.; greatest breadth of same 2.4 mm.; length of hindwing approximately 6 mm.

Head:—Rather small, about 1 mm. wide, blackish in color. *Antennae* (not complete in any specimen) about 2.3 mm. long, with basal segment or scape longer and stouter than the rest; of these, the preserved portions show that they were more or less uniform, cylindrical, and somewhat more than twice as long as broad; total number of segments approximately twenty; color fuscous, possibly with three or four segments near the apex whitish. *Compound eyes* of medium size, placed laterally far apart. *Ocelli* present (clearly marked in at least one specimen) with faint traces of a frontal suture passing across the head from eye to eye and separating the median from the two lateral ocelli. One specimen shows indications of a very wide clypeus stretching practically the whole width between and below the bases of the antennae. *Mouth-parts*:—*Labrum* not visible in any specimen; tip of *mandible* in one specimen shows two or three strong, rather broad teeth; *maxilla* with well-developed palp, five-segmented, the distal segment rather broad and truncated, almost hatchet-shaped (Fig. 5, A, *mxp*); *labium* with much shorter three-segmented palpi (Fig. 5, A, *lp*). The color of the apical two-thirds of the distal segment of the maxillary palp, and of the basal and distal segments of the labial palp, is much darker than that of the rest of these organs.

Thorax:—Prothorax connected with the head by a broad neck region; pronotum very broad, flat, strongly chitinized, blackish in color, somewhat heart-shaped; one or two specimens appear to indicate that it was rugosely sculptured, as in most recent *Perlaria*, but there is no sign of a longitudinal



Fig. 4. *Lemmatophora typica* Sell. Pronotal expansions (x 20). Photo. from Specimen No. 5115, enlarged, by W. C. Davies.

median furrow. The most remarkable parts of the prothorax are the two *pronotal expansions* homologous with the wings (Fig. 4). These are large membranous areas almost circular in outline, except where they meet the convex border of the pronotum, to which they appear to be attached, though in one specimen they seem to pass a little way beneath it. Their diameter parallel to the body axis is 1.7 mm.; their width

transversely from the outermost edge of the pronotum, 1 mm. Each expansion is covered all over with an immense number of tiny hairs or *microtrichia* exactly similar to those found on the wings (Figs. 8, 9), and at first sight appears also to possess a series of slender, branching veins like those of the wings. Careful examination, however, shows that these apparent veins are not chitinized, like true veins, but are the courses of pigment-bands carrying slightly larger hairs, homologous with the *macrotrichia* found on many of the true veins of the wings. They are thus in exactly the same condition as the wing-sheaths of the last larval instar in many Hemimetabola. There are eight or nine of these radiating pigment-bands, of which the longer ones may be branched; some irregular connections also exist between them, resembling cross-veins. It is almost certain that tracheae must have underlain these bands. Each expansion overlaps the mesonotum and the base of the forewing posteriorly.

Mesothorax very wide, almost elliptical in outline, blackish in color and very strongly chitinized, so that it is practically impossible to see the divisions into sclerites. Two or three of the impressions indicate that the sides of the mesothorax projected considerably outwards beneath the base of the forewing, but this may be due to flattening during fossilization. Some of the impressions appear to indicate an enormous, undivided notal plate, but in one at least there are signs of a division somewhat as shown in Fig. 1, while another has slight indications of a median longitudinal furrow, at least anteriorly. A distinct postscutellum appears to have been present.

Metathorax not quite as wide as mesothorax, not so rounded, covered dorsally almost entirely by a large and very strongly chitinized notal plate, appearing undivided in most specimens, except for a slight sign anteriorly of a median furrow, and a fairly well-marked postscutellum.

In Specimen No. 5182, the thorax has become crushed sideways, giving a very good view of the pleurites and coxae, together with almost the whole of the middle leg. Owing to distortion by pressure, it is not easy to make out the various sclerites, but the mesepisternum and mesepimeron are clearly marked, together with two sclerites which appear to belong to the sternum and are probably the eusternum and sternellum.

Legs.—Portions of the legs are preserved in several specimens, the best being the fore legs shown in Specimens 5123 (Fig. 5, B) and 5115 (Fig. 2), and the middle leg shown in

Specimen No. 5182 (Fig. 5, C). *Measurements*:—*Fore leg*, tibia 0.9 mm., tarsus 0.9 mm. *Middle leg*, femur 2.6 mm., tibia 2.5 mm. All three pairs of legs were apparently similar, but the fore legs considerably shorter than the other two pairs. The coxa was broad and short, well rounded in outline, and probably strongly projecting from the thorax; posteriorly, the base of the coxa in middle and hind legs lies in close contact with a marked coxal process from the broad episternum. The trochanter is very short, barely as wide as the femur, and carries (in the middle leg, Fig. 5, C, *tr*₂) a short groove, very

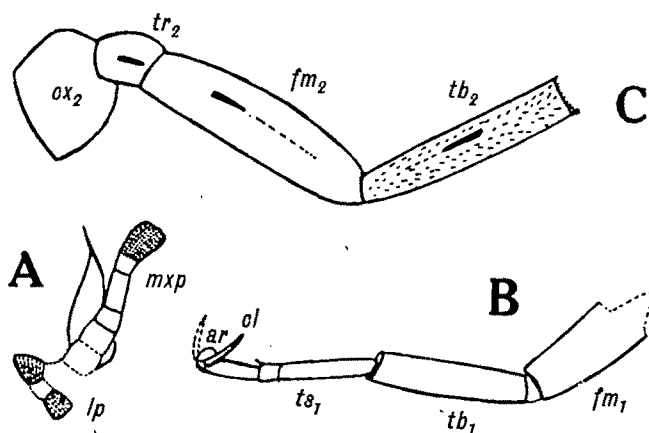


Fig. 5. *Lemnatophora typica* Sell. A, Maxillary (*mxp*) and labial (*lp*) palpi, from Specimen No. 5123a. B, Foreleg from same specimen. C, Middle leg from Specimen No. 5182b, with incomplete tarsus omitted. (x 24.) *ar* arolium, *cl* claw, *cx* coxa, *fm* femur, *tb* tibia, *tr* trochanter, *ts* tarsus.

darkly pigmented. The femur (Fig. 5, C, *fm*₂) is fairly long, broad and flat, with indications of a median longitudinal groove, a small portion of which is darkly pigmented; there is no appearance of armature. The tibia (Fig. 5, B, *tb*₁, C, *tb*₂) is about as long as the femur, but not so wide; that of the middle leg appears to be considerably flattened, with a short, deeply pigmented groove near the middle, and is covered all over with minute but rather stiff hairs or setae; its apical margin is beset with a number of very small spines; the tibia of the fore leg does not show either the groove or the setae, and is neither so wide nor so flattened as that of the middle leg. The tarsus (Fig. 5, B, *ts*₁) is as long as the tibia, but much

slenderer; it consists of three segments, of which the first is the longest, occupying about one-half of the total length; the second segment is very short, the third long and slightly swollen towards its apex, where there is a well-formed pad or arolium (Fig. 5, B, *ar*) placed between two large and strongly formed tarsal claws (*cl*); the first and second segments appear to possess distally a pair of delicate, diverging setae.

Wings.—As in nearly all Orthopteroid insects, fore and hind wings differ considerably both in shape and venation. But for the fortunate circumstance that the right hindwing of Specimen No. 5115 (Fig. 2) projects out at right-angles to



Fig. 6. *Lemmatophora typica* Sell. Forewing, Specimen No. 1004a. Photo. by W. C. Davies.

the body, while the forewings are folded back over its base, but not so as to hide the abdomen, it would have been impossible to correlate the venations of the two wings of this species. The true *position of rest* was almost certainly not exactly that of the forewings in Specimen No. 5115, but a more closely folded position covering the abdomen. The hindwings must have been hidden beneath the fore, and had their anal fans folded beneath the anterior portion of each wing, next to the abdomen itself. In Fig. 2, the *left* hindwing is partially withdrawn under the fore, and it will easily be seen how, even in this position, the anal fan must already begin bending downwards as the wing presses against the abdomen during its backward movement from the position shown by the *right* hindwing, which is roughly the position in flight.

Chaetotaxy.—A point of the greatest importance in the study of the wonderfully preserved fossils is the *chaetotaxy* of the wing-membrane and of the veins. The extraordinary perfection of preservation of even the minutest hairs in many of the specimens cannot be reproduced by photography, though the attempt has been made many times in our laboratory. Fig.

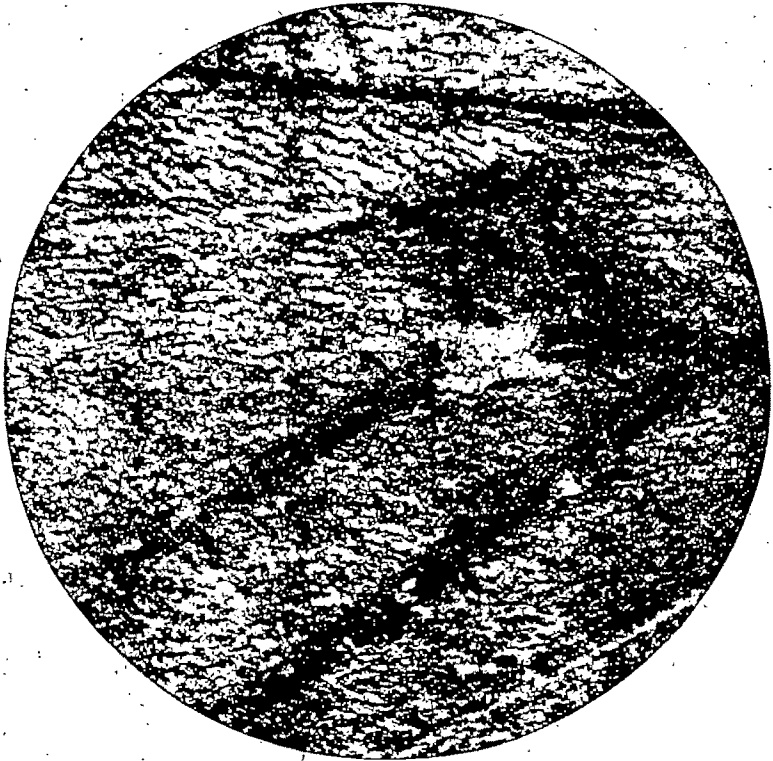


Fig. 7. *Lemmatophora typica* Sell. Portion of forewing of Specimen No. 5192b, much enlarged to show microtrichia of upper surface of wing. (x 70.) Photo. by W. C. Davies.

7 gives the largest amount of magnification that these tiny structures will stand when being photographed with the aid of direct lighting. Fig. 9 gives, for comparison, a smaller portion of the same area of the same wing, carefully drawn with the camera lucida at a higher magnification. The tiny hairs which appear so perfect are not, of course, the *original* hairs of the wing, left stranded on the rock after the chitinous

membrane has dissolved away; they are simply the *perfect impressions* of these hairs, with the original dark pigmentation preserved, as in other parts of the wing. All these minute hairs with which the wing-membrane is covered are true *microtrichia*, viz. fixed hairs developed each from a single hypoderm cell, without special nerve-supply, merely as a fine armature or protective covering for the wing.

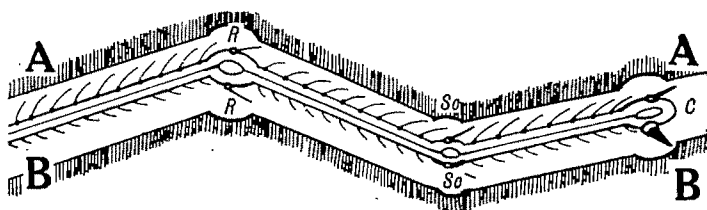


Fig. 8. Diagram to show method of fossilization of portion of a forewing, seen in transverse section. The costa (C), subcosta (Sc) and radius (R) are shown with the chaetotaxy of their upper and under surfaces. AA, the upper piece of rock, taking the impression of the *upper* surface of the wing as a *reverse* impression. BB, the lower piece of rock, taking the impression of the *lower* surface of the wing as an *obverse* impression.

If, now, we take a specimen in which both obverse and reverse of the forewing is preserved, we may note the peculiar fact that, if the specimen is well preserved, with good pigmentation, one impression will be darker and carry denser microtrichia than the other. Exactly the same thing can be noted if we study the upper and under surfaces of the forewing of a recent representative of the order Perlaria, such as *Austroperla cyrene* Newm., the only difference being that, in the Perlaria, the microtrichia are even more minute than they are in *Lemmatophora*, and not so stiff. In the Perlaria, the upper surface of the wing carries the strongest microtrichia; the under surface has them more delicately formed.

Now, if we consider how the two impressions, obverse and reverse, of a fossilized insect wing have been formed, we have to bear in mind that the wing is really a bag with membranous sides, which have come together and fused except along the veins. Such a formation consisted originally, in transverse section, of two layers of hypoderm cells separated by their basal membranes in contact, and each layer protected by its external secretion, i.e., the layer of chitin forming the upper or under cuticular surface of the wing-membrane. Each layer of hypo-

derm cells may produce a smooth cuticle or a cuticle with a definite chaetotaxy. Also, along those portions where an internal space is left for tracheae, blood and nerves, *i.e.* along the wing-veins, trichogen cells may be developed in association with special nerve-endings. The *microtrichia* are purely a cuticular armature; they have no sensory function and no special nerve-supply; in structure they are merely immobile processes of the cuticular layer, and are never inserted into special sockets. The *macrotrichia*, on the other hand, are of the nature of sensory hairs or setae; they are inserted into special sockets, and are mobile on them; normally they only

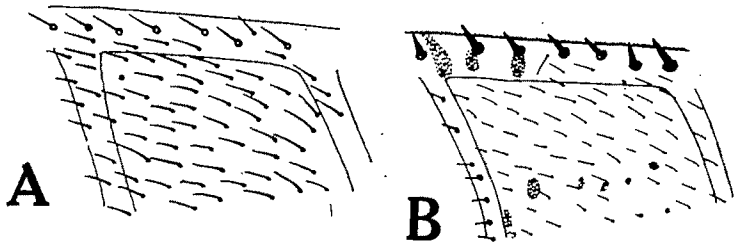


Fig. 9. *Lemnatophora typica* Sell. Chaetotaxy of a small portion of the costal space of forewing of Specimen No. 5161. (x 90.) A, Mirror image of the upper or reverse impression, No. 5161a (turned round for comparison with B) showing the comparatively large microtrichia and the small macrotrichia on the costa. B, Lower or obverse impression, showing the comparatively small microtrichia and the large macrotrichial setae on the costa.

occur along the main veins and their branches. Bearing all this in mind, we may now look at Fig. 8, which is a diagrammatized attempt to indicate how the hard rock lying above and below a fossilized insect wing would take the impressions of the cuticular structures. The diagram shows only the costa, subcosta and radius in cross-section, since that is sufficient for our purpose. The subcosta, being a concave vein, lies in a deep hollow when examined from the upper surface of the wing; the radius, on the contrary, being convex, lies on a high ridge. Thus we see that, after fossilization has taken place, when the rock is split open by the hammer, and the two impressions which we call obverse and reverse are exposed, it is the *obverse* (*i.e.* the impression in which convex veins actually appear convex, and concave veins concave) which is really the impression of the *underside* of the original wing, while the *reverse* (*i.e.* the impression in which convex veins appear

concave, and *vice versa*) is the impression of the *upper side*. Extending our observations now to the chaetotaxy, we conclude that the armature of the *upper side* of the wing will be preserved in the *reverse* of the fossil, while that of the *under side* will be found in the *obverse* of the fossil.

Applying this result to a considerable number of obverse and reverse pairs of forewings of *Lemmatophora typica*, the following interesting result is obtained:

(1) In all well-preserved specimens, the reverse impression appears markedly darker than the obverse. Examination under a fairly high power shows that this appearance is due to the much greater size and strength of the microtrichia.

(2) In a considerable number of obverse impressions, but never in any of the reverse ones, the costal margin carries either large empty sockets, or else the same sockets with large, short, thick setae arranged in a fairly regular row, and directed anteriorly and towards the apex. On the reverse impression, in the corresponding position, a row of rather small, slender macrotrichia can be found; the individual hairs in this row are not much larger than the microtrichia, but have definite sockets.

(3) In a number of specimens, both obverse and reverse, a few rather small macrotrichia can be located on the main veins, and more numerous empty sockets are also noticeable. Only in one or two specimens is anything like a conspicuous macrotrichial armature to be seen on the veins, and in these cases it is best developed on the reverse impression.

Fig. 9, A, B, gives a comparison of the same small area of the forewing taken from the costal area of Specimen No. 5161. This area, in the reverse impression, A, has been turned into a mirror-image, so as to correspond exactly with the actual drawing of the obverse, B. As the reverse gives the impression of the upper side of the wing, we see at once that the microtrichia of that side, in the original insect, were much stronger and longer than those of the under side (obverse). A count of the total number of microtrichia in the area, reckoning only those whose bases lie actually within it, gives a total of 48 microtrichia for the upper side (reverse) and 57 for the under side (obverse), including in the latter three irregular minute lumps of pigment which appear to be imperfectly developed microtrichia. From this we may conclude that the hypoderm cells of the under surface were probably somewhat

smaller and more numerous than those of the upper surface. But this increase in number does little to dispel the impression of much greater hairiness of the upper surface, due to the thicker, longer and more deeply pigmented microtrichia.

We see also, from Fig. 9, B, that the development of strong costal spines is restricted to the under surface of the wing, suggesting that their function may have been to prevent the forewing from folding backwards too far, and thus exposing the weaker costal margin of the hind to damage. In the area figured, there are seven large costal spines on the under surface of the costa, and seven corresponding weak macrotrichia on the upper surface.

The presence of the strong costal setae is the diagnostic character relied on by Sellards for distinguishing his species *L. hirsuta*, as already mentioned. We see clearly now that *L. hirsuta* Sell. is merely a synonym of *L. typica* Sell., having been described from an obverse of that species with the macrotrichia of the costa preserved.

In defining the genus *Lemmatophora*, Sellards states that "the wing-membrane is minutely scaly." Even under a low power lens, the membrane is clearly seen to be hairy, not scaly. True scales are a specialization of macrotrichia, and are developed on the wing-membrane only in the two orders Trichoptera and Lepidoptera; in the latter they are universal, but in the former they are found only in a comparatively few highly specialized types. Scales also occur on the veins in certain genera and families of the orders Copeognatha, Neuroptera, Planipennia and Diptera, but never on the wing-membrane in these orders. In the Orthopteroid orders scales are never found, either on the wing-membrane or on the veins.

The above detailed description of the chaetotaxy is given because it appears to throw a flood of light on the actual conditions of fossilization of insect wings and offers the first definite proof that the armature of the upper and under surfaces of the wing is separately preserved in the fossil. Clearly, conditions must have been extremely favorable for fossilization of delicate insect wings in these Kansas beds, for I know of no other fossil insects in which the delicate microtrichia are so perfectly preserved; if the conditions were such that the wing-membrane became macerated and decayed before fixation of the impression in the hardening mud, this could not have happened. We must therefore conclude that these

insects were very quickly covered with mud which may have hardened rapidly under the influence of heat, and was again covered by further layers before disintegration could take place. The perfection of the pigment pattern also indicates that this was the case.

Shape of the Wings:—The forewing may be described as oval, with the apex moderately well rounded, and the breadth approximately one-third of the length. Sellards gives the following measurements of his type specimen:—*length* 7 mm., *breadth* $2\frac{1}{4}$ mm.; this gives a ratio of 3.11. The following are the measurements of the fourteen most perfect forewings in the Yale University Collection, arranged in ascending order for lengths, with their corresponding breadths and ratios of length to breadth:

Length:—6.2, 6.3, 7.2, 7.2, 7.6, 7.6, 7.7, 8.0, 8.0, 8.1, 8.2, 8.2, 8.4, 8.9 mm. *Average* 7.7 mm.

Breadths:—1.9, 1.9, 2.4, 2.4, 2.4, 2.5, 2.6, 2.7, 2.8, 2.5, 2.6, 2.8, 2.7, 3.1 mm. *Average* 2.5 mm.

Ratios:—3.3, 2.9, 3.0, 3.0, 3.1, 2.9, 2.9, 2.9, 2.8, 3.2, 3.1, 2.9, 3.4, 2.8.

Highest ratio 3.4; *lowest ratio* 2.8; *average ratio* 3.02.

The *hindwing* is slightly shorter and much broader than the fore and has the apex not quite so rounded. Apart from the additional width due to the anal fan, the width of the hindwing measured at the level of the end of vein Cu_{1b} is slightly greater than that of the fore at the same level. The width of the anal fan taken transversely to 1A at the level of the end of the fifth branch of 2A (*i.e.* approximately the greatest breadth of the fan) is about the same as the greatest breadth of the forewing. Taking the hindwing as a whole, with the fan spread out, the greatest breadth at right angles to the costal margin lies at a level between the ends of the third and fourth branches of 2A, and is half as wide again as the greatest breadth of the forewing. At the end of the *vena dividens* (Cu_2) there is a marked break in the contour, or reëntrant angle, such as is found in all *Perlaria* at the present day, except only in the *Eustheniidae*.

Coloration:—Many of the forewings preserved show the color-pattern of this species perfectly (see Fig. 6). The wing was probably subhyaline in life, with small areas of either fuscous or dark brown pigment. The most marked of

these is a squarish area enclosing usually two well-defined cross-veins between M and Cu₁, beginning at the point of origin of Cu_{1c} and extending distad to just beyond the second cross-vein. The basal half or two-thirds of the pterostigmatic region is also more or less deeply pigmented, the pigment covering the somewhat irregular end of Sc, where it comes into relationship with the basal pterostigmatic veinlets arising from R₁. All the cross-veins in the distal part of the wing are more or less narrowly pigmented; sometimes they are barely chitinized but still quite markedly pigmented, thus recalling the primitive condition of a pigmented band which appears to have preceded the formation of true veins. Broader areas of moderate pigmentation may be developed between Rs and MA just distad from the origin of the former, and also between MA and MP₁ above the origin of the latter. Sometimes the basal portion of the anal area is pigmented. There is considerable variability in the color-pattern, and this is increased by the marked variation in the number and positions of the cross-veins. The costal veinlets are not accompanied usually by bands of pigments surrounding them, but their pigment is confined to the actual chitinizations. The condition shown in *Lemmatophora typica* strongly resembles that seen in such recent Perlaria as *Zelandobius confusus* (Hare) (see Tillyard, 1923, p. 206, Fig. 6) and *Zelandoperla maculata* (Hare) (l.c., p. 214, Fig. 15), both belonging to the family Leptoperlidae. The hindwing is devoid of pigmentation except for a slightly darkened area in the pterostigma and the two cross-veins below it.

Wing-Venation.—In the *forewing* (Fig. 1), the costa is slightly and evenly arched. Sc is nearly straight and gives off a complete series of costal veinlets more or less irregularly spaced; these number from nine to about fifteen from base up to beginning of the pterostigmatic area. The distal portion of Sc is very variable; it may approach the costa very closely and end up well before the pigmented area of the pterostigma begins, but more commonly it runs on beyond this point, often curving away again from the costa after nearly touching it. In this case, the distal end becomes more or less broken up and connected with the first two or three pterostigmatic veinlets lying in the pigmented area. It is interesting to note that the forked condition of the subcostal trachea shown in many recent Perlaria represents a condition closely allied to this, only with

the distal portion more downcurved so as to come secondarily into contact with R_1 below it.

R_1 is a strong convex vein, almost straight in its distal half, then curving slightly upwards to the beginning of the pterostigmatic region, and finally ending up on the costa well before the apex; it gives off a simple R_s at about half-way or a little before. A little basad from the origin of R_s is a single strong, oblique cross-vein between R_1 and Sc , sometimes followed by one or two more cross-veins rather close together; occasionally there are also one or two cross-veins placed more basally between R_1 and Sc . In the pterostigmatic area the number of veinlets is variable; generally there are from three to six in the pigmented portion, and one or more of these may be forked, while in the hyaline distal portion there may be none at all, or from one to three. Frequently the end of Sc comes into relationship with the first two or three pterostigmatic veinlets by connecting crossveins, as in Fig. 1; but this venation is usually very weakly formed, and it is not easy to determine what point is the actual end of Sc . Between R_1 and R_s there are usually from two to four cross-veins, irregularly placed.

The media (M) presents a very special problem in this genus, and gives us a character which is valid for the whole order Protoperlaria. Instead of being a concave vein entirely, as in most recent insects, it has a formation similar to that of Cu , i.e. it arises as a concave vein, and then divides into an anterior convex portion, MA , and a posterior concave portion, MP . The basal portion, M , lies close up to R for about one-fourth of the wing-length, and then begins to diverge from it. Slightly before the level of the origin of R_s , the chitinization of M becomes obsolescent, and it divides into MA and MP . The former becomes, almost at once, again strongly chitinized, and runs very nearly straight to the apex of the wing, without branching; the latter continues obsolescent to a point about two-thirds of the wing-length, where it divides into MP_1 and MP_2 , the former arching up away from the common stem, and becoming chitinized again, while the latter, continuing the line of the common stem, is only chitinized for a short distance apically. Irregular pigmented cross-veins, variable in number, occur here and there between all these veins. The importance of this formation in the interpretation of the nature of the median vein in the order Perlaria will be explained when we have dealt with the hind wing.

The cubitus (Cu) has a very characteristic form. Starting as a concave vein well below M, it forks quite close to the base into an upper convex Cu_1 and a lower concave Cu_2 ; the latter forms the *vena dividens* separating the anal area from the rest of the wing, and runs in a straight line to a point on the posterior margin little more than one-third of the wing-length from the base. Cu_1 is a very strong vein, slightly arched upwards; at about one-fourth of the wing-length it again divides, giving off a lower branch Cu_{1o} which runs nearly straight and parallel with Cu_2 to the wing-margin. The upper



Fig. 10. *Lemmatophora typica* Sell. Hindwing, perfect specimen, No. 5150a. Photo. by W. C. Davies.

branch, however, is strongly arched, and again divides at about the level of the origin of Rs into Cu_{1a} and Cu_{1b} , giving a strong and well-developed apical fork. The two strong cross-veins joining M with the upper branch of Cu_1 in the pigmented area already mentioned above are usually present; in some cases there may be a forked vein, or three or four simple veins closer together; more rarely one or two cross-veins are visible in the pigmented extension between the two branches of Cu_1 . The cross-veins between the branches of Cu are usually very few and highly variable. In contrast with the very strong chitinization of Cu_1 , that of Cu_2 is very light, in some specimens almost obsolescent.

The *anal area* of the forewing is of interest in that it shows definitely only two convex veins, 1A and 2A, connected together by two strong and obliquely placed cross-veins. 2A has a short posterior branch descending on to the anal margin before the anal angle, which is quite well marked in many specimens, though rather rounded in others. This variability in form closely parallels that to be seen in the anal angle of the recent species *Austroperla cyrene* Newm. in the order Perlaria. One or more weak cross-veins may be present between Cu_2 and 1A.

The venation of the *hindwing* (Fig. 10) differs markedly from that of the fore in the following characters:—Sc is shorter, ending up on costa not much beyond half-way along the wing; it is somewhat curved concavely to the rest of the wing, and the number of costal veinlets is reduced and highly variable; one specimen shows eight or nine, very weakly formed, and two of them forked; another shows a basal humeral veinlet followed by five weaker and more obliquely placed; while a third shows only the humeral veinlet. (This variability, again, closely parallels that of *Austroperla cyrene* Newm.) The pterostigmatic area is less strongly pigmented than in the forewing and may lack veinlets in the pigmented portion, or it may carry weak veinlets throughout. Rs arises closer to the base than in the forewing, well before half-way; after descending obliquely for a short distance, *it unites for a considerable stretch with MA*; these two veins again separate under the beginning of the pterostigmatic region, and run divergently and slightly curved, without branching, to the wing-margin; MA ends up, as in the forewing, at the apex. M arises close under R as in forewing, but leaves it just distad from the level of the humeral veinlet, bending down to fuse for a short but variable distance with the upcurving Cu_1 below it. After leaving Cu_1 again, M becomes obsolescent; close under or a little distad from the level of the origin of Rs, it gives off the upwardly arching MA which very soon fuses with Rs; the main stem of M then continues on as the concave MP, which remains obsolescent until near the wing margin, and is a straight, unbranched vein. Cu arises far below M and almost at once gives off the upwardly arching, convex Cu_1 , which, after fusing with M for a short distance, diverges from it obliquely as a strongly chitinized, straight vein, forking about halfway into Cu_{1a} and Cu_{1b} . Cu_2 is lightly chitinized, and continues as the absolutely straight *vena dividens* to the

reëntrant angle on the posterior margin, separating the contour of the anal fan from that of the rest of the wing.

The *anal fan* of the hindwing again contains definitely only two veins, both convex. 1A is unbranched and runs, with slight bending only, close beneath Cu_2 ; it is strongly chitinized basally, but weaker distally. The rest of the expanded fan is supplied by five radiating branches of 2A; of these, the first two arise from a common stalk with the other three, very close to the base of the wing, forming a deeply forked vein; the third and fourth branches are simple and straight; the fifth bends downwards and slightly backwards towards the anal margin of the wing for about one-third of its length only, or less, and then bends forward slightly again so as to run to the posterior margin just distad from the rounded anal angle; at this bend or angle, it gives off a short spur to the anal margin of the wing.

Returning now to our study of the *media*, we see at once that the *Perlaria* offer a close parallel in the partial fusion of this vein with Rs in the hindwing, which is a constant throughout the whole order, and in no other order. But the fused portion of M in the hindwing of the fossils is always MA, never MP, which is almost entirely obsolescent. One must conclude, then, that it is highly probable that the *media* of existing *Perlaria* is entirely formed from MA. If so, then it should be a convex vein, not a concave one as in most other insects. An examination of the forewing of any species of *Perlaria* shows that this is actually the case; the *media* is just as prominently convex as the cubitus and the radius! This fact is so clearly noticeable that one wonders how it could have escaped comment for so long. One can only conclude that the sweeping condemnation of the value of convex and concave veins given by Comstock has had the effect of persuading everybody to ignore such an awkward but outstanding fact as this one.

The condition of the *media* in *Perlaria* was a continual puzzle to Comstock, who could not clearly understand how, in such a primitive order, a vein which, on his hypothesis, ought to have been four-branched, exhibited a two-branched condition which was, according to his theory, highly specialized. Had he given any weight to the convexity and concavity of veins, the solution of this problem could scarcely have escaped him, even without the aid of fossils.

The resemblance of the forewing in *Lemmatophora* to that of a primitive Perlarian type, such as one of the Austroperlidae or Leptoperlidae, is strong enough to attract our attention and invite further study. But when we look at the hindwing, the resemblance is so close that it forces itself on our notice. The two outstanding points here are the fusion of Rs with MA, and the whole structure of the anal field. The long, simple 1A running nearly straight and very close under Cu_2 occurs in all Perlaria, while the five-branched condition of 2A, with the first two branches stalked, forming a large fork, is the primitive condition for the order, and is retained almost in every detail (including the posterior spur of the fifth branch) in such forms as *Isogenus*. The interpretation of these veins has been partially obscured by Comstock and Needham's insistence on the recognition of three anal veins, though the tracheation only indicates two in both wings. Now we see that the fossils agree with the tracheation, and there is no need to demand a fusion of the basal portions of tracheae 2A and 3A in order to make the scheme conform to a hypothetical primitive type with three anals.

The full study of the lines of descent of the order Perlaria from the Permian fossil order Protoperlaria cannot be given here, but must await a complete study of all the types represented in the Kansas beds. *Lemmatophora*, though lying very close to the actual ancestral line, is probably not one of the direct ancestors of the Perlaria. We may expect that, out of the multitude of forms known to be present in these beds, we shall be able to select at least one as the actual ancestor of the order, or, alternately, that we may even be able to recognize, as already differentiated out, two or more distinct types, leading to different families or groups of families within the Perlaria.

Abdomen.—The *abdomen* in *Lemmatophora* is short and rather broad. The length is about two and a half times the breadth, and is about equal to the combined length of the three larger thoracic segments, i.e. 3.5 mm. The coloration is very dark, and the tergites appear to have been smooth and of a tough, leathery consistency.

One of the most remarkable and unexpected discoveries is shown in Fig. 11, taken from the abdomen of Specimen No. 5147. At the sides of the three most anterior segments, and most clearly on the left, there can be seen projecting flaps or *paranota* almost suggesting lateral gills. These are paler than

the tergites and were evidently thin, membranous expansions homologous with those of the pronotum, though not so well developed, and, as far as can be seen, lacking pigment bands, though there is a slight suggestion of hairiness about them. On the right side in Fig. 11, on two of the more posterior segments, the same expansions can be made out, but apparently *on edge*; this suggests that the insect had power to flatten them against the sides of the abdomen. These paranotal expansions appear to me to be exactly similar to those already known in the Paleodictyopterous genus *Stenodictya* (see Handlirsch, 1908, Atlas, pl. viii, Fig. 20); this is rendered even more probable by the fact that *Stenodictya* also possessed the homologous prothoracic structures.



Fig. 11. *Lemmatophora typica* Sell. Abdomen of male, Specimen No. 5147a, showing paranotal expansions resembling gills (best seen on left side of the two most anterior segments). Note also the terminal appendages, for comparison with Fig. 12. (x 16.) Photo. by W. C. Davies.

I have not been able to detect the organs in any other specimens in which the abdomen is preserved. This is not to be wondered at, provided we assume that they were somewhat delicate structures. Their absence might be accounted for either by maceration before fossilization, or by their becoming detached from the abdomen, or perhaps they may merely have become folded against the abdomen and pressed down beneath the tergites. The preservation of even two or three or a set of such structures, as in Specimen No. 5147, must be considered a fortunate chance, and has enabled us to complete the picture of the morphological structure of this wonderful extinct insect type.

Assuming, as seems probable, that Specimen No. 5115 (Fig. 2) is a female, I am not able to indicate any special structures at the end of the abdomen which could be interpreted as external genitalia. Specimen No. 5147, however, does show some structures which can be interpreted as the male genitalia (Fig. 12). There are two hard, chitinous processes arising from the postero-lateral angles of the last abdominal segment and projecting inwards and slightly posteriad; these appear to me to be the *paraprocts* (*pa*). Their tips are separated by a hard and apparently upstanding median process from the tenth tergite, which is strongly suggestive of the *copulatory hook* (*cp*) found in the *Perlaria*, and developed from that sclerite. This process is rather narrow anteriorly, where the tips of the

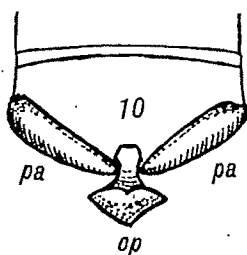


Fig. 12. *Lemmatophora typica* Sell. End of abdomen of male, drawn from Specimen No. 5147a, to show copulatory appendages. *cp* copulatory hook or process of tenth tergite. *pa* paraproct, 10 tenth tergite. (x 18.)

two paraprocts meet it, but posterior to this it expands into a triangular process with slightly concave margins. The whole appearance is very suggestive of a strongly upcurved tergal process, excessively hardly chitinized, which has become pressed down vertically during fossilization, without breaking or flattening, thus keeping its shape and symmetry.

The *cerci* (Figs. 1, 2) are well developed, 2.8 mm. long, fairly slender, tapering, with indistinct segmentation, especially basally. They are covered with delicate hairs, and show a remarkable color-pattern; the basal portions for about 0.6 mm. are pale; then follows a band of dark pigmentation, 0.5 mm. long, then a shorter pale ring, 0.3 mm. long, and finally the distal half of the cercus is darkly pigmented again. This striking coloration is beautifully shown in the photograph in Fig. 2.

Variety *quadrifurcata* nov.:—Specimen No. 5192a-b (Fig. 13) shows a forewing with a very striking variation in the structure of the first cubitus, which has a large additional fork on Cu_{1a} . The details of venation at the end of Sc and in the

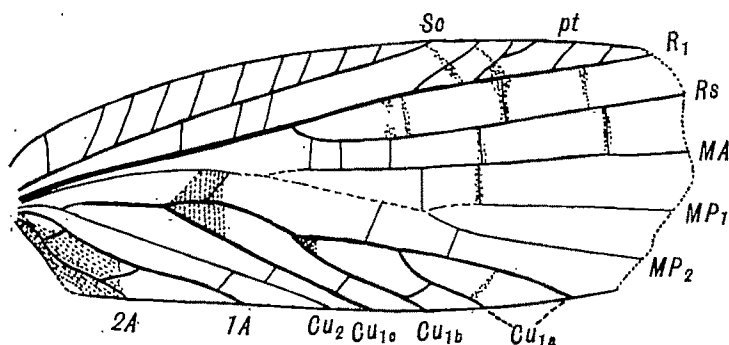


Fig. 13. *Lemmatophora typica* Sell. Venational variation *quadrifurcata*, showing a large extra fork on Cu_1 . Lettering as in Fig. 1.

pterostigmatic region are also considerably different from normal *typica*, but the chaetotaxy is exactly the same and the dark pigment patch around the first fork of Cu_1 is present, so that I prefer to class this wing merely as a venational variant

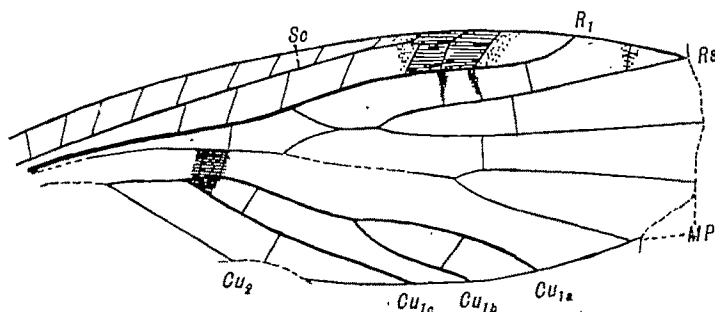


Fig. 14. *Lemmatophora typica* Sell. Venational variation *conjuncta* nov., showing partial fusion of Rs with MA. Specimen No. 5200.

of the type of *delicosa*, only more striking, rather than make it the type of a new species.

Variety *conjuncta* nov.:—Specimen No. 5200 is a rather poorly preserved forewing having Rs partially fused with MA, as shown in Fig. 14. This is the only specimen of *L. typica*

which I have so far found in the Yale Collection with this peculiarity, but it assumes great importance from the relative frequency with which an exactly similar fusion takes place in other genera of the family Lemmatophoridae, as will be shown in Part II of this work.

Variety *quadrimedia* nov.:—Specimen No. 5201 is a rather small forewing, well-preserved, with MA distally forked, as in Fig. 15. This specimen also is unique, and illustrates another tendency towards venational variation which is much more developed in the genus *Artinska* Sellards, as will be shown in Part II.

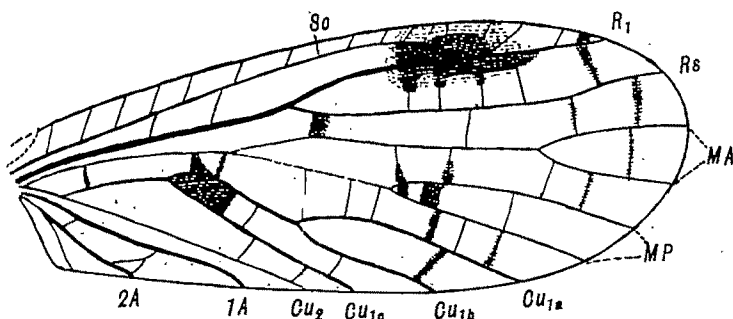


Fig. 15. *Lemmatophora typica* Sell. Venational variation *quadrimedia* nov. showing extra apical fork on MA. Specimen No. 5201.

Types:—Holotype No. 1162 in Dr. Sellards' Collection; paratypes in the same collection, Nos. 30, 32, 1266, 1376, 1377, 1379, 1050 (var. *delicosa*), 1047 (*hirsuta*), 149 (*elongata*).

All the new material in the Yale University Collection may be classed as topotypes. This material is classified into groups herewith, and the location of each specimen is indicated:—

Practically complete specimen, showing head, thorax, forelegs, wings, abdomen and cerci (unique):—No. 5115, Yale University Collection (Figs. 1, 2). The right forewing of this specimen exhibits the variation *delicosa*, the left forewing is normal *typica*.

Specimens showing parts of body and wings, usually with one or both pronotal expansions present:—Nos. 5116 a-b, 5117 a-b, 5118, 5119 a-b, 5120 a-b, 5121 a-b, 5122, 5123 a-b, 5124 a-b, 5125 a-b, 5126 a-b, 5146 a-b, 5147 a-b (abdomen with paranotal expansions, Fig. 10), 5148, 5149, 5182 a-b. All in Yale University Collection except Nos. 5118, 5146a and the counterparts of other specimens labelled b, which are in the

Cawthron Institute Collection. *Total*.—Sixteen specimens, of which twelve have counterparts.

Forewings, well preserved.—Nos. 1004 *a-b* (Fig. 6), 5127 *a-b*, 5128, 5129, 5130, 5131 *a-b*, 5132 *a-b*, 5133 *a-b*, 5134 *a-b*, 5135 *a-b*, 5136, 5137 *a-b*, 5138 *a-b*, 5139, 5140, 5141, 5152 (with hindwing), 5155 *a-b* (with small larval form also), 5184 *a-b* (forewing with extra apical fork on Cu_{1b}, hindwing also present, 5199 (forewing with extra apical fork on Cu_{1b}), 5192 *a-b* (var. *quadrifurcata* nov., Fig. 13), 5201 (var. *quadrimedia* nov., Fig. 15), 5202, 5203 *a-b*. All the above in Yale University Collection except Nos. 5129, 5139, 5141 and the counterparts of other specimens labelled *b*, which are in the Cawthron Institute Collection; but both Nos. 5155*a* and 5155*b* are in the Yale University Collection, to show the differences between the chaetotaxy of upper and under sides. *Total*.—Twenty-three specimens, of which thirteen have counterparts.

Hindwings, well-preserved.—Nos. 5142 *a-b*, 5143 *a-b*, 5144, 5145 *a-b*, 5150 *a-b* (perfect, Fig. 10), 5151 *a-b*, 5152 (with forewing on same block), 5153, 5186 *a-b*, 5188, 5191, 5204 (with meso- and metathorax present). All in Yale University Collection except Nos. 5153, 5191 and the counterparts labelled *b*, which are in the Cawthron Institute Collection. *Total*.—Thirteen specimens, of which seven have counterparts.

Fragmentary or poorly preserved wings.—Nos. 5154, 5156 *a-b*, 5157 *a-b*, 5158 *a-b*, 5159, 5160, 5161 *a-b*, 5162 *a-b*, 5163 *a-b*, 5164 *a-b*, 5165, 5166, 5167 *a-b*, 5168 *a-b*, 5169, 5170 *a-b*, 5171 *a-b*, 5172 *a-b*, 5173, 5174, 5175, 5176, 5177, 5178, 5179, 5180, 5181 *a-b*, 5183 *a-b* (with thorax), 5185 *a-b*, 5187, 5189, 5190, 5200 (var. *conjuncta* nov., Fig. 14), 5205. All the above in Yale University Collection except Nos. 5159, 5166, 5169, 5174, 5176, 5178, 5180, 5189 and the counterparts labelled *b* which are in the Cawthron Institute Collection; but both 5161 *a-b* and 5162 *a-b* have been retained complete in the Yale Collection as examples of the chaetotaxy, while 5163 *a-b* is retained in the Cawthron Collection for the same purpose. *Total*.—Thirty-four specimens, of which fifteen have counterparts.

Grand totals.—Eighty-six specimens, of which forty-five have counterparts, making a grand total of one hundred and thirty-one actual specimens of this single species!

Lemmatophora anomala Sell.

Sellards, 1909, p. 163.

This species is described by Sellards in two lines, as follows:—"One branch of the media of this species coalesces for a short distance with the cubitus. Length of wing, 7 to 8 mm.; width $2\frac{1}{2}$ mm. Type No. 1089."

There is no specimen in the Yale University Collection showing the above peculiarity, which seems to be somewhat unlikely to have occurred in this genus. A careful examination of the type is needed. Possibly it is only an aberration from *L. typica* Sell.

Lemmatophora minuta (Sellards).

(Figs. 16-18.)

Lisca minuta Sellards, 1909, p. 163 and Fig. 21, p. 164.

Sellards described the genus *Lisca* and the species *L. minuta* in six lines, which have been already quoted in this Part in discussing the genus. The figure and measurements agree so

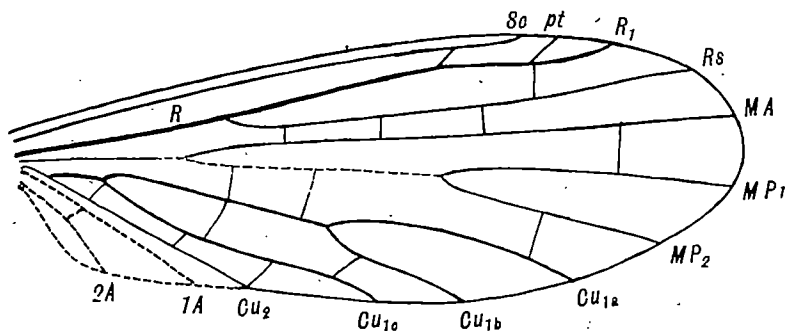


Fig. 16. *Lemmatophora minuta* Sell. Forewing, Specimen No. 5196, with missing anal area restored from No. 5197. Length 5.5 mm.

closely with my drawings of a small species of *Lemmatophora* quite commonly represented in the Yale University Collection that I have no hesitation in stating that the character of the partial fusion of *Rs* with *MA*, on which Sellards based his genus *Lisca*, is merely a chance aberration or venational variation, and that this species should be removed to the genus *Lemmatophora*. Curiously enough, I have not found a single

specimen in the Yale Collection in which the partial fusion of Rs with MA occurs in this species; but, on the other hand, a similar fusion can be found in almost every other species throughout the family, and I have even indicated its occurrence in the type species (Fig. 14).

The description given by Sellards being inadequate, some additional details are given here:—

Length of forewing 4.8 to 5.8 mm., most of the specimens being about 5.3 mm.; *greatest breadth* 1.6 to 1.9 mm.; *ratio of length to breadth* always about 3.0, except in var. *pusilla* (Fig. 18).

At first sight, the forewings of this species resemble those of the family Delopteridae, but a closer inspection shows that the subcosta, though faint, runs right along to the pterostig-

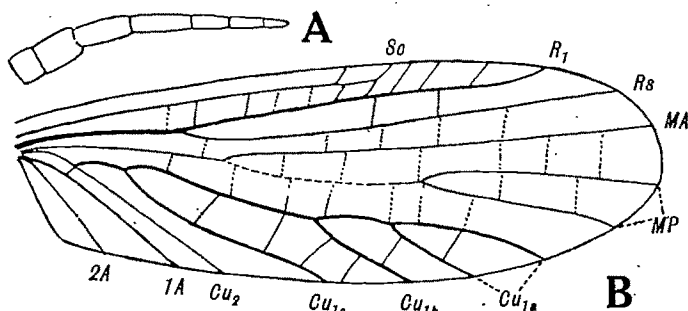


Fig. 17. *Lemmatophora minuta* Sell. A, Cercus ($\times 36$), from Specimen No. 5240. B, forewing from specimen No. 5208 with four-branched Cu_1 .

matic region, while the structure of Cu_1 differs very greatly from that of the latter family. Sc keeps fairly close to the costa throughout; its apical end is very variable, as in other species of the genus, and there is usually some fusion with the first one or two pterostigmatic veinlets. Both veinlets and cross-veins are for the most part very faint and poorly chitinized; it is possible that the costal veinlets are not always present, but I have been able to make them out in one specimen completely, and partially in two or three others. A similar condition prevails in the living genus *Austroperla* of the order Perlaria.

There is considerable variation in the positions of the origins of Rs and MA; they may be at the same level, or either of

them may be well basad from the other. The two extreme conditions are shown in Figs. 16 and 17. Rs is straight or slightly curved. MA is straight and ends up a little above the apex of the wing. MP is consistently forked about half-way from its origin, and the upper branch of the fork always ends up at or very close to the apex of the wing. Cu₁ in most specimens shows the normal condition for the genus *Lemmatophora*, viz. three branches of which the most posterior, Cu₁₀, arises near the base from the arched basal piece of Cu₁, while the other two form a distal fork at about half-way along the anterior branch. There is, however, considerable variation in the condition of Cu₁ in individual specimens; a striking formation, exactly equivalent to var. *quadrifurcata* of *L. typica* Sell. (Fig. 13), is shown in Fig. 17; another specimen shows a small terminal fork on Cu₁₀, while a third shows a larger fork on the same vein. One specimen (No. 5209) shows a large fork on Cu_{1b}. The anal area is very variable; 1A is only slightly curved, in some cases practically straight; 2A short and usually more curved, diverging much from 1A; anal cross-veins variable or absent; anal angle varying from a very definite obtuse angle to a gentle rounding.

The *hindwing* is well preserved only in one specimen (No. 5209); it is similar in venation to that of *L. typica*, but the subcosta is straight and there are no signs of cross-veins anywhere. The fusion of Rs with MA is well marked. Cu₁ forks at about half-way. 1A lies very close to Cu₂. The fork of 2A arises nearer to the base than in *L. typica*, this being probably a more primitive condition.

The antennae, complete in Specimen No. 5210, are elongate, about 3 mm., very slender, with about thirteen segments. The *prothoracic* lobes are proportionately smaller than in *L. typica*, measuring only about 0.5 mm. or at most 0.6 mm. in width. The *tarsi* resemble those of *L. typica*, being three-segmented, with the basal segment longest and the second segment very short. The abdomen is complete in one specimen (No. 5211) and shows ten well-formed segments with small paranotal expansions. The cerci (Fig. 17, A) are complete in Specimen No. 5240; they are 1 mm. in length and consist of about seven distinct segments, of which the first two are rather broad and short, the rest longer and narrower, tapering markedly to the apex, which is very pointed; there is no marked color-pattern on them like that of *L. typica*.

The general coloration of the body appears to have been dark brown or fuscous. The forewing in most specimens is completely but lightly suffused with brown pigment; a few specimens are subhyaline, while some are only pigmented around certain cross-veins. The following varieties are well-marked enough to deserve special names:—

Var. *pusilla* (Fig. 18):—This form differs from the type almost enough to deserve specific rank, were it not for the fact that connecting links are to be found intermediate between it and the type. The wing is very short and broad; length only 4.3 mm., breadth 1.6 mm., ratio of length to breadth 2.6. It will be seen that the breadth is the same as that of the smaller specimens of the type form, but the length is reduced and con-

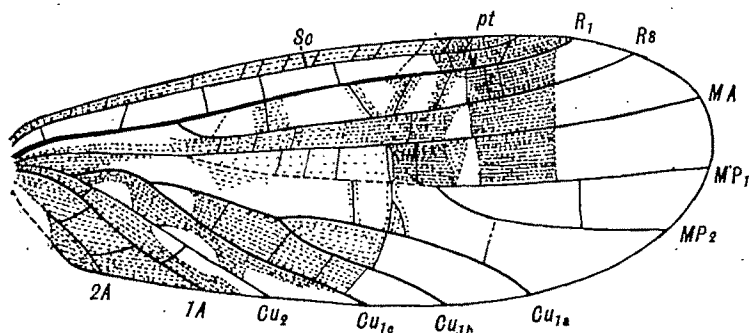


Fig. 18. *Lemmatophora minuta* Sell. var. *pusilla* nov. Forewing, from Specimen No. 5193. Length 4.3 mm.

sequently the apex is much more broadly rounded. I am inclined to regard this simply as an aberrancy of form. The wing is heavily and irregularly colored with brown pigment, only the apical fourth being completely hyaline; in Fig. 18, an attempt has been made to indicate the limits of the coloring, but much of it is somewhat indistinct. The cross-veins are somewhat more distinct and numerous than in the type form and MA is not arched at all at its origin. *Type*:—Specimen No. 5193 in Yale University Collection.

Var. *semitincta*:—Forewing with the anterior and basal half from end of MA obliquely across to end of 1A deeply pigmented, the rest subhyaline. *Type*:—Specimen No. 5216a in Yale University Collection and counterpart No. 5216b in Cawthron Institute Collection.

Var. *obscurata*.—Forewing deeply pigmented all over.
Type.—Specimen No. 5197 in Yale University Collection.

Types.—*Holotype* (forewing with Rs partially fused with MA), Specimen No. 916 in Sellards' Collection. Topotypes from Yale University Collection:—Specimens No. 5193 (var. *pusilla*), 5196 *a-b*, 5197 (var. *obscurata*), 5198, 5206 *a-b*, 5207 *a-b*, 5208 *a-b* (Fig. 17, with four-branched Cu₁), 5209 *a-b* (body, fore and hind wings), 5210 *a-b* (body and both forewings), 5211 *a-b*, 5212 *a-b*, 5213, 5214 *a-b*, 5215 *a-b*, 5216 *a-b* (var. *semitincta*), 5217 *a-b*, 5218 *a-b*, 5219, 5220, 5221, 5222, 5223 *a-b*, 5225 *a-b*, 5226, 5227, 5228 *a-b*, 5229, 5230, 5231 *a-b*, 5232 *a-b*, 5233, 5234 *a-b*, 5235 *a-b*, 5236, 5237 *a-b*, 5238, 5239, 5240 *a-b*, 5241 *a-b*, 5242, 5243, 5244, 5245 *a-b*, 5246 *a-b*, 5259 *a-b* (body and forewings), 5260 *a-b*, 5261. *Total*.—Forty-seven specimens, of which twenty-six have counterparts, making a grand total of seventy-three actual specimens of this species.

All the above specimens are in the Yale University Collection except Nos. 5198, 5230, 5234, 5236, 5239, 5242 and the counterparts labelled "b" except No. 5235b. Specimen No. 5235 *a-b* is very poorly preserved, showing part of the body and wings, but is worthy of note as having been the first insect specimen discovered by the Yale University Expedition in 1921.

Lemmatophora reducta n. sp.

(Fig. 19.)

This species is only represented by a fragment of a forewing, measuring about 4.3 mm. in length, and indicating a total wing-length of about 6 mm. The outstanding characters of the species lie in the coloration and in the form of the cubitus. The wing is pigmented with pale brown, but this is chiefly developed along the main veins and broadly around the cross-veins, in such a manner as to leave fairly large, oval or irregular, hyaline areas in between. Cu₁ has only two branches, of which the anterior is somewhat irregularly waved.

Type.—*Holotype forewing fragment*, Specimen No. 5224a in Yale University Collection; counterpart, No. 5224b in Cawthron Institute Collection.

This completes our survey of the genus *Lemmatophora* Sell. In Part II we shall take up the study of the remaining genera

of the family Lemmatophoridae, of which it is only necessary to remark here that venational variation in them is so rampant that their classification is not at all an easy matter. The student who desires to understand the systematics of this

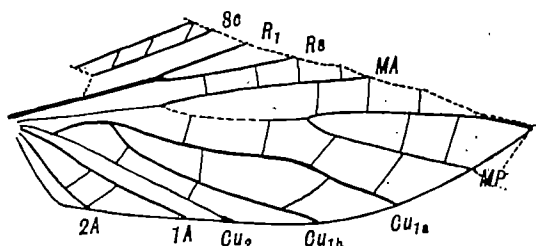


Fig. 19. *Lemmatophora reducta* n. sp. Forewing fragment, Specimen No. 5224. Length 4.3 mm.

group must first grasp clearly this marked tendency of the venation to vary. For this purpose, I have deliberately emphasized the venational variations to be noted in the genus *Lemmatophora* itself.

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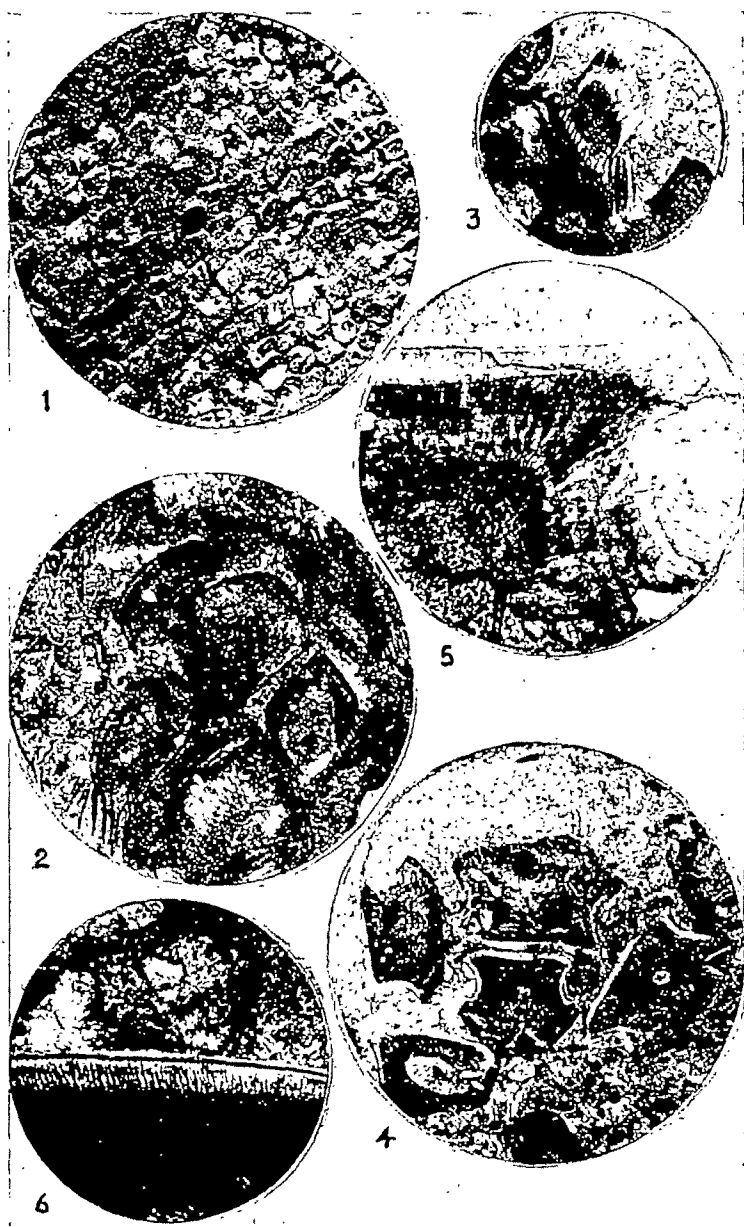
A NEW AMERICAN THELODUS.

HENRY C. STETSON.

INTRODUCTION.

This paper is intended as a preliminary report on the first of the Coelolepidae to be described from North America. In it I have included a short discussion of the relationships of this puzzling family in the light of Stensiö's (15) notable new monograph of the Cephalaspidae. My thanks are due to Dr. William MacIntosh of the Natural History Society of New Brunswick, who gave me much assistance in the field, and for whom I take pleasure in naming the new species, and also to Dr. Leigh Hoadley for advice concerning the histological structure of the scales.

The first Coelolepid was described by Agassiz in Murchison's "Silurian System" under name of *Thelodus parvidens* Ag. from scattered tubercles in the Ludlow Bonebed (8). Later Pander (9) described similar scattered tubercles from the Oesel Limestone. Agassiz thought that these tubercles were teeth, but later writers, McCoy (7), Woodward (20), and Rohon (12), came to the conclusion that they were shagreen denticles, and therefore the Coelolepids were Elasmobranchs. Until the description of the complete specimen of *T. pagei* (Powrie) by Traquair (17) this was the prevailing view. The fish is completely covered with shagreen denticles, and the body is depressed, not unlike that of a modern ray, but recognizable jaws and teeth are absent, and this point was, to him, sufficient to exclude the family from the Elasmobranchs. Accordingly he placed them in the Heterostraci, but emphasized the fact that the presence of placoid scales undoubtedly pointed to an Elasmobranch relationship. In a later paper Traquair (18) includes under the order Heterostraci, the Coelolepidae, the Drepanaspidae, the Psammosteidae, and the Pteraspidae. These four families he supposes to be a closely related series, based on the gradual fusion of separate placoid tubercles into a solid shield. Smith Woodward (21) adopts this classification, merely including *Psammosteus* and *Drepanaspis* in the same family. In addition, *Astraspis* and *Gemündina* have been added to the order by later writers, though the inclusion of both forms is open to question.



Figs. 1-6.

Stensiö (15) cuts off the Heterostraci from any connection whatever with the Elasmobranchs. The Coelolepidae, therefore, have had every conceivable interpretation put on them. A short discussion of the position of this family will be taken up in the concluding paragraphs. It is necessary first to see what genera are at present included in the family; and then to proceed with a description of the new species now under consideration.

In regard to the Coelolepidae, Traquair (18, p. 828) says: "This family was instituted by Pander for the genera *Coelolepis*, Pander; *Thelodus*, Agassiz; *Nostolepis*, Pander; and *Pachylepis*, Pander. Of these *Nostolepis* and *Pachylepis* are synonyms of *Thelodus*, while *Coelolepis*, in my opinion, falls under the same category." This genus, then, together with *Lanarkia*, a smaller, more spiny form from the Devonian (18), are the only valid genera in the family.

THELODUS MACINTOSHI, n. sp.

Specific characters.—Scales are smooth, diamond-shaped and somewhat convex, becoming more elongate on the lateral margins. Distinguished from *T. parvidens* Agassiz by the presence of long spines on the posterior borders of the marginal scales. Pulp cavity well developed, with the opening somewhat constricted.

Fig. 1. A well preserved mosaic of denticles from the center of a large specimen. About $\times 4\frac{1}{2}$. Holotype M. C. Z. 2035.

Fig. 2. Horizontal section through the crowns of marginal denticles, showing posterior spines. In some cases they are broken off short. About $\times 21$. Paratype M. C. Z. 2036.

Fig. 3. Horizontal section through the crown of a marginal denticle, showing very long, posterior spines, broken on the left side. About $\times 21$. Paratype M. C. Z. 2036.

Fig. 4. Longitudinal section of median denticles, showing the stud-like shape of crown, neck and base. The dark substance is dentine, the thin, light-colored layer of the crown is enamel. Note the contour lines and pulp cavities. About $\times 21$. Paratype M. C. Z. 2037.

Fig. 5. Longitudinal section of a median denticle. Note the dentine tubes radiating from the central pulp cavity. Note the contour lines, and also the light-colored layer of enamel with its tubules. About $\times 110$. Paratype M. C. Z. 2037.

Fig. 6. Longitudinal section of a median denticle. The black substance is dentine. Note the two layers of enamel across the middle of the circle, and the projections of dentine matrix giving rise to the enamel tubules of the basal layer. The tubules of the thin outer layer of enamel are too small to be visible at this magnification. Part of this layer shows as a dark line because of a slightly yellowish tinge, in contrast to the whiter upper portion. About $\times 110$. Paratype M. C. Z. 2037.

Description.—This species is known from specimens in several concretions. When broken open, the surface is seen to be thickly studded with a mosaic of diamond-shaped tubercles covering the surface of the concretion (Fig. 1). All the specimens have been so badly distorted that no clear idea of the form of the animal can be obtained. In general, specimens are broad at one end and become narrower towards the other, which, by reference to the figure of *T. pagei* from Forfarshire, would seem to indicate a ray-like form. (Traquair 17, Fig. 1.) *T. pagei* measures about 12 inches in length. The largest of my specimens measures exactly that in its longest dimension, but the concretion is broken off short while still carrying nearly the full width of the animal. If, therefore, the proportions of *T. pagei* can be taken as typical, another 8 or 10 inches should be added to make up the total length of the largest specimen of *T. macintoshi*. The other concretions are about the length of *T. pagei*. There is nothing to indicate which is the dorsal and which the ventral side.

The scales in the center of the body are large, and nearly square, measuring $\frac{3}{4}$ to 1 mm. in length, and about half that in width. They closely resemble *T. parvidens* from the Ludlow Bonebed, although somewhat larger. Approaching the margins, the tubercles become smaller and more elongate, and some of them are markedly thorn-shaped. These marginal tubercles possess a feature which distinguishes the species from *T. parvidens*, namely, the presence of long spines on what are probably the posterior margins of the tubercles (Figs. 2, 3). The posterior point of the tubercle is extended in a spine about $\frac{1}{2}$ mm. long. The point of origin is flush with the surface. On either side are five to six spines originating progressively lower down on the tubercle, and growing progressively shorter. When viewed in cross section these spines approach the surface at an angle. The spines stop at the two lateral angles of the tubercle. The marginal and posterior scales do not make such a close-set mosaic as do those in the center, and only the tip of the central spine overlaps any neighboring scale. In longitudinal section, the outline of each scale exhibits a well-developed, overhanging crown, a somewhat constricted neck, and a base not quite as large as the crown, giving the stud-like appearance characteristic of the genus (Fig. 4).

Horizon and Locality.—This species was obtained from

Cunningham's Brook, Nerepis, New Brunswick. In this same horizon are found *Ceratiocaris pusillus* Matthew, *Bunodella horrida* Matthew, *Cyathaspis acadica* (Matthew). Matthew (6) considered these beds to be Niagaran in age, but it seems more probable that they are really Ludlow or Downtonian.

STRUCTURE.

Tomes (16, p. 444) considers that the hard surface layer of plagiostone teeth when it is thin, as in the rays, "differs little in histological characters from similar layers upon mammalian teeth. . . . But where thick, it diverges in many respects from the usual type of enamel." After examining the chemical and physical characteristics of his material, and particularly the mode of its development, he concludes that this substance really shares the nature of both dentine and enamel, but that it varies among the different families. That of the rays is the most like true enamel. It is obvious that in fossil material, either teeth or scales, we have usually only the histological characteristics to depend on. He finds the dentine to be of two types, osteodentine, and the ordinary, fine-tubed variety. The Lamnidae all have dentine of the former variety, while in the rays, and some of the transitional forms such as *Carcharias*, *Galeus*, and *Scyllium*, the dentine is always fine-tubed.

In *T. macintoshi* the dentine is fine-tubed. The tubes radiate from the pulp cavity, branching and anastomosing freely throughout their course (Fig. 5). It has the typical layers, or contour lines, exhibited by modern dentine, showing that its mode of growth must have been the same, i. e., by addition to the walls of the pulp cavity. The basal plate, although composed of dentine, possesses fewer tubes, and gives the impression of being a less dense variety than that of the crown and also appears to contain considerable carbonaceous matter. This is probably caused by the penetration of the connective tissue fibres into the plate, as is the case in modern Elasmobranchs. In these modern forms, as the scale grows older, the basal plate becomes larger and is penetrated more deeply by the connective-tissue fibres. In the skates the base is very large and "the dentine may gradually change to a softer tissue, composed of numerous trabeculae surrounding irregular spaces" (Goodrich 2, p. 752). The scales of *Thelodus* represent the early, primitive condition before the

fusion of dentine and connective-tissue had progressed far. Rohon (12, Taf. ii, Figs. 50, 52) figures a longitudinal section of *T. glaber* (Pander), and of *T. parvidens*, and in them the dentine is of exactly the same type, and shows well-marked contour lines, although the finer details of the enamel described below are not apparent, due to the size of his figures.

In Tomes' fossil material the dentine had become stained a reddish-brown, sharply differentiating it from the enamel which remains almost colorless. The same type of staining is present in my sections. The line of contact between dentine and enamel is a crenulated one. Projections of the brown dentine matrix penetrate short distances into the enamel, which is divided into two layers. The inner is about .035 mm. thick, the outer about .01 mm. Each of the dentine projections, which enters the thicker, basal layer of enamel, contains one or more tubes, which branch into twos and threes, thus giving rise to the tubules of the enamel. These tubules traverse the basal layer of enamel, branching and anastomosing only to a very slight extent, their courses being for the most part parallel. On reaching the thin outer layer, they in their turn break up into exceedingly fine tubules, which run parallel to each other almost to the surface of the scale. This last set begin to be visible at a magnification of about 400 diameters. Tomes' sections show the same type of structure (16, Pl. 17, Figs. 1, 2, 4), although the dentine penetrates the enamel more deeply, and the tubules of both layers, as well as of the dentine, are coarser. It should be remembered that his sections are cut from teeth, while mine are from scales. In both cases the structure is essentially the same (Fig. 6).

Thus we have a typical placoid denticle, histologically homologous in every part with modern shagreen denticles, and with the fossil selachian teeth cited above, particularly with that type found in the rays.

RELATIONSHIPS.

Traquair left the Coelolepidae in the Heterostraci because they were agnathous, but repeatedly emphasized an Elasmobranch affinity, and states that in his opinion, they "have had a common origin with the primitive Elasmobranchs" (17, p. 602). Stensiö keeps them in the Heterostraci but decides that this order, on account of the structure of the other individuals in it, has no connection whatever with the Elasmo-

branches, but is derived, together with the Osteostraci, from the "primitive Ostracoderms." The Coelolepidae are included because the ridged appearance of the endoskeleton, in the single whole specimen of *T. pagei*, resembles in outward form the endocranium and visceral endoskeleton of the Cephalaspids. This puts us in the rather anomalous position of having one group of fish, whose skin bears a shagreen of typical placoid scales, completely cut off from the only other group that have this same characteristic type.

There are three possible ways out of this situation. First, that the Heterostraci really do have Elasmobranch affinities as Traquair supposed; second, that Stensiö was mistaken in his homologies in this instance, and that the Coelolepidae alone belong in the Elasmobranchs; and lastly that *T. pagei* does not belong in the family at all.

In regard to the first point, we must accept Stensiö's results for the time being, as he has been the most recent worker on *Pteraspis* (14). Kiaer (5, p. 130) is not wholly convinced, however, and as he is at present preparing a monograph on Pteraspids, we must await his results before proceeding further.

The second point rests entirely on the outward resemblance of the endocranium, and visceral endoskeleton, of the Cephalaspids, to the curious markings in *T. pagei*. There is no trace of mouth or jaws. It is admitted that the presence of an orbit is doubtful. Assuming that the tail was heterocercal, Traquair thought that the animal presented its dorsal aspect. The hypocercal tail was then unknown, so that, lacking further evidence, we are not even sure which is dorsal and which ventral. It might even be pointed out with equal fairness by advocates of the Arthropod Theory, that judging by outward appearances alone, the endoskeleton of this particular individual bears a certain resemblance to the groovings on the head shield of *Limulus* or *Bunodes* (Patten 10, Figs. 13, 152, 155).

The body form of *Thelodus* is known only from *T. pagei*, and two smaller species from the Downtonian. Of these *T. pagei* is by far the largest, and is the only one, as I have said, that shows any trace of an endoskeleton. Those species in which the scales have been examined histologically in any detail, including *T. parvidens*, the type of the genus, are known only from isolated tubercles, or at most from patches of scales. In other words, where the placoid type of scale

is known to exist, the body form is unknown. Nevertheless *T. pagei* is covered with the typical shagreen of smooth scales, and they are known to contain a pulp cavity, which make it, in all probability, a true Coelolepid.

No one, I think, will question the fact that scale structure is an important method of determining relationships in all orders of fishes. It is, in fact, the main argument advanced to hold the Heterostraci together. Traquair supposed that evolution in the family proceeded along the lines of plate fusion, from the simple denticles of *Thelodus*, through *Psammosteus* and *Drepanaspis*, to *Pteraspis*. The "scales" meanwhile acquired a very complicated basal portion of laminated and cancellous tissue, and even the superficial layer became so modified that its structure was not that of a placoid scale. Stensiö reverses the process, and considers that it proceeded along the lines of plate reduction, and that *Thelodus* is the end product (15, pp. 330-334). In the Cephalaspids he distinguishes three layers (15, pp. 32-41, pls. 63-72). The basal layer is of true, laminated bone, with cells between the laminae, and it is transversed by numerous, ascendant, vascular canals. The middle layer is characterized by indistinct lamination, and abundant, branching, vascular canals. The superficial layer is always perforated by fine, circular pores, which are the external branches of the inner radiating canals. He considers this type of plate-structure the direct homologue of that described in the Pteraspidae by the earlier writers (15, pp. 317-320). It is difficult to see how either can be compared in any way with *Thelodus*. In the latter there is no basal bony layer, there is no trace of any intermediate vascular layer, and even the superficial layer, which is the one we should naturally try to homologize, exhibits little similarity. As figured by Stensiö (15, pl. 72), in the Cephalaspids at least, the superficial layer is not easily comparable to the typical Elasmobranch dentine and enamel. The dentine is of quite a different type, and its shining surface is not the homologue of the selachian enamel described by Tomes, or of that found in *Thelodus*. Furthermore, the circular pores that pierce the surface point to an altogether different type of structure.

In the case of *Pteraspis* and *Psammosteus*, the correspondence with *Thelodus* appears, at first sight, to be somewhat closer. Even here, however, it is not by any means certain that the radiating canals of the superficial layer can be directly homologized with branching, anastomosing tubules of Elas-

mobranch dentine, and it is still more doubtful if there is anything directly comparable to Elasmobranch enamel. As I have mentioned above, the superficial layer is the only part that can serve as a basis for comparison, as no Elasmobranch has the laminated, bony, basal layer displayed by the Ostracoderms.

Although the mouth and jaws of *Thelodus* are unknown, they probably were not true Gnathostomes, and therefore these fishes are included in the Agnatha. This is an exceedingly comprehensive group, and needs to be defined. At present it includes those animals which do not have the type of jaws thought to be derived from the first visceral arch. But the mouth structures of the various members of this group, i. e. the Anaspids, Pteraspids, Cephalaspids (Kiaer 4, 5) Antiarchi, (Patten 10) and Cyclostomes, are as difficult to homologize one with another, as is any one of them with the Gnathostomes. It can be pointed out in this connection, that though it is practically impossible to homologize the present condition of the branchial basket in *Petromyzon*, with the visceral skeleton of other fishes, it is a well known fact that *Bdellostoma* bears two true gill arches, and a possible hyoid, as part of its branchial basket (Ayers and Jackson, 1). This being the case, it seems difficult to escape the fact that the Cyclostomes, so often called primitive, are merely the degenerate descendants of fishes with a true visceral skeleton, and therefore, necessarily, with jaws. It will be remembered that many writers have homologized the large cartilage of the rasping tongue with the lower jaw. The Agnathous condition in the Cyclostomes, therefore, seems to be due to degeneracy from higher forms, rather than to a "primitive" condition, and therefore it can hardly be homologized with the type of mouth found in the Paleozoic Agnatha.

In the case of this ancient group, it is becoming increasingly apparent that the sharp line drawn between the Agnatha and the Gnathostomi is a very artificial one, and that we must recognize in some of these early forms the ancestors of our later jaw-bearers. The "agnathous" state may well have been the first stage in the evolution of the vertebrate mouth, later to be superseded, after the acquisition of a visceral skeleton, by the present functional mouth. What type of mouth structure existed in *Thelodus* is, for the present, unknown, but enough has been said to indicate some of the dangers in using an "agnathous" condition as a basis of classification.

It should be noted in addition that among Devonian jaws, there are two interesting variations to what is thought to be the orthodox type, namely, that found in the Acanthodians and in the Arthrodires.

To return to the case in point, whatever the ultimate relationship of Coelolepid to Ostracoderm may prove to be, so much is clear, namely, that the former possesses typical placoid scales. As we now understand it, if any reliance can be placed in placoid scales, this points to an undoubted Elasmobranch relationship and, therefore, the Coelolepidae should be classified among the earliest sharks, lying on, or near, the main stem. *T. pagei*, like the Ostracoderms, has the depressed form of a mud-groveller, but this is explained more logically at present by parallel development, due to a similar mode of existence. *T. scoticus* Traq., *Lamarkia spinosa* Traq. and *L. horrida* Traq. on the other hand, are all distinctly fusiform.

CONCLUSION.

Whether or not the Ostracoderms prove to be related to primitive Elasmobranch stock, the position of the Coelolepidae is not affected in the least. If relationship can be proved, the two groups are so widely differentiated that the split must have occurred long before the Ludlow. The heavily armored forms among the Ostracoderms can only be regarded as a blind offshoot from the main stem that kept a primitive type of mouth structure to the end. It is not to highly specialized, heavily armored types that we must look for ancestors of new strains. The Coelolepids, on the other hand, are the only forms known at present that can be considered an early link in the Elasmobranch chain, before the acquisition of the secondary mouth. As the Elasmobranchs are their nearest relatives, they should be returned to that class, and probably given ordinal rank. This may not be a final or a satisfactory grouping, and when we can interpret with greater certainty the significance of the primitive, "jawless" mouth, it will doubtless be superseded. In the meantime, our present knowledge serves to remove them from the Ostracoderms, and group them once more with those fishes with which they have most in common.

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THE NATURE OF THE FIRST MOTION IN THE
CHILEAN EARTHQUAKE OF
NOVEMBER 11, 1922.

PERRY BYERLY.

It is well known that several distinct types of earthquake waves are propagated from the focus of an earthquake. The first type to be recorded on seismographs at a little distance is a longitudinal or compression-rarefaction wave. This wave penetrates the earth to some depth, its path being determined by refraction which is due to an increase of velocity with depth.

It is found that for a given earthquake in certain directions from the focus the first wave to be recorded is a compression while in other directions it is a rarefaction. A study of this distribution is important in pointing toward the nature of the first motion of the rock at the source or focus.

A study of the seismograms of the Chilean earthquake of November 11, 1922, recorded at stations throughout the world shows that the distribution of compressions and rarefactions is as follows:

At Algiers in North Africa, at stations throughout Europe and North America, at Tokyo, Honolulu, Apia, and Manila, the first motion was a compression. At Batavia (Java) and at the South African stations, Good Hope and Johannesburg, the first motion was a rarefaction.

The bearing of Algiers from the epicenter was $N 50^{\circ} E$ while the bearing of Manila was $N 143^{\circ} W$. Between these in a northerly direction lay 20 other stations, all showing a first compression.

The bearing of Batavia was $N 175^{\circ} E$ while that of Johannesburg was $N 117^{\circ} E$. Between these (southerly) lay Good Hope. And these stations showed a first rarefaction. Thus it is seen that the bearings of stations showing a first compression subtend an angle greater than 193° and less than 302° at the epicenter. Within this region all stations recorded first compression, while without it all stations recorded a rarefaction.

The following table gives the various stations with epicentral distances, Δ , and bearing from the epicenter. The epicenter has been located by Macelwane and Byerly¹ at 29° south latitude, 70° west longitude.

¹ Publication of the Carnegie Institution, in press.

Stations recording a first compression.

Station	Δ	Bearing
Algiers	95°	N 50° E
Rocca di Papa	104°	N 50° E
Vienna	109°	N 45° E
Coimbra	90°	N 42° E
Uccle	103°	N 39° E
Hamburg	107°	N 38° E
De. Bilt	104°	N 38° E
Cambridge (Mass.)	71°	N 1° W
Northfield	73°	N 2° W
Ottawa	75°	N 4° W
Cheltenham	68°	N 6° W
Washington	68°	N 6° W
Balboa	39°	N 15° W
St. Louis	70°	N 17° W
Spokane	89°	N 30° W
Victoria	91°	N 32° W
Berkeley	83°	N 39° W
Lick Observatory	82°	N 39° W
Tokyo	154°	N 67° W
Honolulu	99°	N 70° W
Apia	93°	N 108° W
Manila (P')	162°	N 143° W

Stations recording a first rarefaction.

Station	Δ	Bearing
Batavia	145°	N 175° E
Cape of Good Hope	73°	N 120° E
Johannesburg	84°	N 117° E

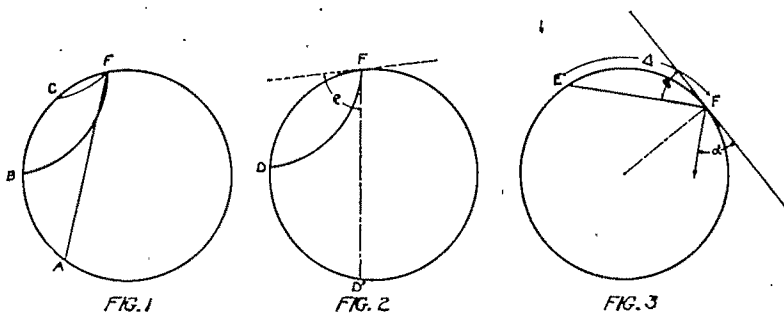
Nakano² has shown that a single, impulsive force, acting in an infinite, isotropic, elastic solid, should cause an impulse of rarefaction in one-half of the solid and one of compression in the other half, the division plane being through the line of application of the force and perpendicular to it. It is evident that a force so applied would produce along the line of application a compression in one-half and a rarefaction in the other half of the initially disturbed volume. Since both the compression and the rarefaction would be propagated with the velocity of longitudinal waves, that half of the solid including the region of compression would first receive the compressional phase, while that half including the rarefaction would first receive the rarefactional phase. The shear component of the initial strain would propagate with lower velocity.

The application to the case of the earth involves the intro-

² Seismological Bulletin of the Central Meteorological Observatory of Japan, 1, No. 3, 1923.

duction of heterogeneity in the radial direction and the introduction of boundaries. The latter, while it will cause some modification in the amplitude of motion, should not cause a material influence on the general nature of the first phase. But the former, namely heterogeneity with depth, must be considered.

Suppose an initial distribution of compression and rarefaction within a small volume at the focus caused by a single impulsive force. Consider a plane bisecting the small volume such that the strain on one side of the plane has a compressional component, that on the other side a rarefactional component, i.e., the plane is perpendicular to the force. All rays leaving the focus from the compressional side of the volume



will be compressional, in first phase, while all rays leaving the rarefactional side will be rarefactional, in first phase. But the radial heterogeneity of the earth causes a bending of the rays so that if the above mentioned plane were extended so that it cut the earth's surface it would *not* so divide the surface of the earth that the first phase of the waves arriving at stations on one portion would be compressional and on the other rarefactional.

This is shown in Fig. 1. The circle represents a great circle of the earth. Line FA represents the trace of the plane bisecting the focus. It is clear that ray FC will be the path of a wave different in first phase from that following path FB.

However, if it be desired to find the position of that plane through the focus which bisects the regions of initial compression and rarefaction, given the distribution of first compressions and rarefactions at stations at various points on the earth's surface, the following procedure may be used. In Fig. 2 let F represent the focus and D a station, FDD' being a great circle of the earth. Draw FD' such that the acute

angle between FD' and tangent to the earth's surface at F is equal to the angle of departure from the focus, e , of ray FD , i.e., FD' is tangent to FD at F . For symmetrical rays the angle of departure from the focus is equal to the angle of emergence. D' may be called the extended position of D . It may be obtained by the following relation: arc $FDD' = 2e$. If the extended positions of all the stations concerned be so found and these positions be located on a large globe, the problem may then be treated as though the earth were homogeneous and the stations actually located in the extended positions. The problem is then to find the possible positions of a plane that divides the earth into two parts such that on the surface of one of them lie the extended positions of all stations registering a first compression and on the other those showing first rarefaction. Each possible plane will of course cut the earth in a circle which will pass through the epicenter (considering depth of focus negligible with respect to the other distances involved). For a given position of this plane the corresponding possible causal force may be obtained. This force will pass through the focus perpendicular to the plane. Referring to Fig. 3, where θ is the acute angle between the plane and a great circle perpendicular to the surface trace of the plane at the epicenter, the dip of the line of the force will be

$$a = 90^\circ - \theta = 90^\circ - \frac{\Delta}{2}$$

where Δ is the diameter (measured along a great circle) of the circular trace of the plane on the earth's surface. Thus the smallest possible circle dividing the surface of the earth into extended regions of first compression and first rarefaction will be that one which will give a corresponding maximum dip to the causal force. And the largest circle will give the least dip.

If $N\beta^\circ E$ represents the bearing at the epicenter of the center of the area intercepted by the plane on the earth's surface, then it represents also the sense of the horizontal component of causal force. Thus the circles which make the maximum acute angles with each other at the epicenter will give the extremes of bearings for the causal force.

In the case of Chilean earthquake values of e , the angle of departure of the ray, for the various values of epicentral distance were taken after Gutenberg.³ These values are only

³ Seiberg's, "Erdbebenkunde," pp. 305 and 303, Jena, 1923.

approximate and thus the extended positions of the stations may be in error by a few degrees. However, this is sufficiently accurate for the purpose. For Manila, at an epicentral distance of 162° , e was taken as 90° , since P' was the first arrival. This value is obviously too large but probably not greatly so. (See Gutenberg's figure in op. cit.) For Batavia, where a diffracted P (not P') was the first arrival, the value of e was taken similar to that for an epicentral distance of about 120° .

The smallest circle in this case passed through the extended positions of Batavia and Johannesburg with a center near 57°E , 64°S . The largest passed through those of Apia and Manila with a center near 77°E , 56°S . The circles giving extreme bearings were those through Algiers-Batavia, center near 28°E , 27°S , and Apia-Johannesburg, center near 129°E , 65°S .

It was found that the possible direction of the causal force varies from $\text{N } 63^\circ \text{ W}$, corresponding to a dip of 6° , through north to $\text{N } 10^\circ \text{ E}$ with a dip of 5° . The dip varies from 0° , with a direction of $\text{N } 18^\circ \text{ W}$, to 12° with a direction $\text{N } 21^\circ \text{ W}$. These limits may be in error by several degrees owing to uncertainties in angle of emergence and in construction. And it is evident that the limiting dip of 0° is too small since it is excluded by the actual positions of the stations receiving first compressions and rarefactions. These did not lie on separate hemispheres. This error was introduced by assuming a value of e for Manila (90°) which was obviously too large. However, it was given as a limit.

It is concluded that an impulsive force acting at the epicenter (29° S , 70° W) and directed within the limits stated above would have been a sufficient cause for the first movement of the earthquake as recorded at seismographic stations over the surface of the earth. Such a distribution of first motions seems to exclude as a source of the motion a sudden expansion throughout the initial volume, as in an explosion, or a sudden contraction.

It has been assumed throughout this discussion that the first motion has remained longitudinal in type throughout its path and that it has suffered no reflections, i.e., there was no possibility of a change in phase. This is in accord with the accepted view.

THE OCCURRENCE OF TRIDYMITE AND CRISTOBALITE IN A GRANITIC XENOLITH.

A. ALLEN WEYMOUTH.

The xenolith that furnished the material for this study is a rounded mass of disintegrated granitic rock which was found in a road cut along the Little Salmon River, ten miles north of New Meadows, Idaho. It was embedded in a palagonite tuff which was formed by the quenching of a presumably Miocene basaltic flow in a small lake. The boulder was probably picked up by the flow as it advanced over a low hill before reaching the lake. This field evidence was furnished by Mr. R. E. Fuller.

By using the methods of sedimentary petrography the xenolith was found to contain the following minerals:

- | | |
|---------------|------------------|
| 1. Quartz | 7. Garnet |
| 2. Orthoclase | 8. Iron oxide |
| 3. Oligoclase | 9. Zircon |
| 4. Muscovite | 10. Tridymite |
| 5. Biotite | 11. Cristobalite |
| 6. Chlorite | |

Silica is represented by three different forms.

(1). *Quartz*—very plentiful and often stained with iron oxide. The grains are more or less crowded with sillimanite and zircon inclusions. The sillimanite inclusions are felted or in long laths and broken prismatic portions of the laths; sometimes the larger individuals show faint pleochroism from colorless to faint pink. Pyramidal terminations are noticeable on the larger laths. The zircon is usually in stumpy, prismatic crystals.

(2). *Tridymite*—in isotropic flakes. Many of these flakes show well developed prismatic and basal cleavage. Mean index of refraction 1.475. There are many inclusions of the same type as that in the quartz grains. In some cases fan-shaped groups are present.

(3). *Cristobalite*—the optical properties of this mineral are exactly the same as those given for tridymite, except the index of refraction, which is approximately 1.485. Only a few grains of this mineral are noticeable, however, while the tridymite makes up nearly 1% of the rock.

The occurrence of tridymite and cristobalite has been discussed by Lacroix,¹ Fenner,² Scott,³ Thomas,⁴ Shand,⁵ Ras-

¹Lacroix, A., Les Enclaves des Roches Volcaniques (1893).

tall,⁶ and many others. It has been found that under ordinary conditions the inversion temperature of quartz to tridymite is $870^{\circ} \pm 10^{\circ}$, to cristobalite $1470^{\circ} \pm 10^{\circ}$.² As it is probable that silica does not crystallize in any other form than quartz from a batholithic mass, we may assume that the inversion to tridymite and cristobalite was produced by the heat of the enclosing basalt. Fenner noted that cristobalite was best produced in the laboratory by using sodic tungstate as a catalyst. Sodic tungstate probably never occurs in a basaltic magma as a catalyst, although it may be possible that the volatile constituents of the basalt play a catalytic rôle, allowing in this way the formation of a small amount of cristobalite. This mineral may have formed within a zone against which there was a concentration of the volatile constituents. Therefore, if it be assumed that the cristobalite was produced catalytically it might be expected that the tridymite would far exceed the cristobalite in amount. Furthermore, as the xenolith was carried but a short distance before it was chilled, it would be entirely possible to have the three forms, quartz, tridymite, and cristobalite, present within the one mass.

For the purpose of comparison the writer studied the artificially prepared cristobalite in a Harbison-Walker, Western Star silica brick, which he obtained through the courtesy of Prof. Hewitt Wilson, of the Ceramics Department. The brick had been heat-treated at approximately 1400°C and is composed of 70-75% cristobalite and 25% quartz and glass. Tridymite was not detected. The glass, at first glance, is the most noticeable substance but on close examination it is found to be fringed with cristobalite, which is present also along fractures. The cristobalite has a mean index of refraction slightly higher than 1.485. The cristobalite is easily distinguished from the glass, which has a much higher index of refraction. In every way the cristobalite of the silica brick is identical to that found in the xenolith, except for its complete lack of inclusions.

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¹ Fenner, C. N., Stability relations of silica minerals, this Journal, 36, 331-384, 1913.

² Scott, A., The inversion in silica bricks, Trans. Ceram. Soc., 17, 137-151, 1917-18; The constitution of silica bricks, *ibid.*, pp. 459-474.

³ Thomas, H. H., Xenolithic Tertiary minor intrusions in Mull, Q. J. Geol. Soc., 78, pt. 3, 229-260, 1922.

⁴ Shand, S. J., Eruptive Rocks (London, 1927), pp. 21, 51, 143.

⁵ Rastall, R. H., Physico-Chemical Geology (London, 1927), pp. 216-220.

THE GREAT BAHAMA BANK. STUDIES IN MARINE CARBONATE SEDIMENTS.

RICHARD M. FIELD.

Coral reefs have been studied by biologists and geologists for a number of years. From a geological point of view, the "coral reef controversy" had added piquancy to geological literature and has served to illustrate the principles of multiple working hypothesis as applied to geological problems. Attention has been focused principally upon the reef flat and outer slope or reef wall, and any work done on the lagoon facies of atolls was largely incidental to such problems as the origins and depths of lagoons and the characters of the encircled islands. While several papers have added to our knowledge of the agents contributory to the formation of the reef rock, sedimentary and stratigraphical investigations have been largely incidental. Unfortunately, modern coral reefs, both atolls and barrier reefs, have little, if any, relation to Paleozoic stratigraphical problems, both sedimentary and paleontological, with the exception of the lagoon facies.

In the summer of 1918, the writer visited the Marine Biological Station at Tortugas, then under the direction of the late Dr. Mayer, for the purpose of studying the interesting deposits of fine calcium carbonate which occur as the lagoon facies of coral reefs, and to which the late Dr. Drew¹ called particular attention by his important paper on bacterial origin of calcium carbonate. This material proved to be interesting not only from the point of view of its origin, but also because of its chemical and physical characteristics. In a preliminary paper² the writer took the liberty of calling this type of sediment Drewite in order to distinguish it from other fine-grained marine carbonate deposits, such as the chalks which are usually described as containing a relatively high percentage of foraminifera and clastic material.³ Dr. Kindle⁴ later proposed

¹Drew, G. H., On the Precipitation of the Calcium Carbonate in the Sea by Marine Bacteria, and on the Action of Denitrifying Bacteria in Tropical and Temperate Seas, Carnegie Inst. of Washington, Publication 182, 9-45.

²Field, R. M., Investigations Regarding the Calcium Carbonate Oozes at Tortugas, and the Beach-Rock at Loggerhead Key, Year Book 18, Carnegie Inst. of Washington, 197-198, 1919.

³Tarr, W. A., Is the Chalk a Chemical Deposit?, Geol. Mag. 252-264, 1925.

⁴Kindle, E. M., Nomenclature and Genetic Relation of Certain Calcareous Rocks, Pan-Am. Geol. 39, 365-372, 1923.

the term Vaughanite for what may be the lithological equivalent of Drewite. Experiments with fresh Drewite from the deeper parts of the lagoon at Tortugas show that this sediment has many of the physical attributes of "clay"—among the most important of which is its exceeding plasticity. By means of highly artificial experiments under the tropical sun, and later, in the laboratory, a number of interesting intraformational structures were produced very similar to, if not identical with, those which have been described from the Paleozoic limestones and dolomites from many parts of the world.⁵ Unfortunately, most of our studies on marine carbonates have been made in the neighborhood of *typical*, modern coral reefs, organic structures, which the writer has good reason to believe are peculiar to Post-Paleozoic and possibly to Post-Mesozoic times. Paleozoic "reef societies" were very different from those of to-day although we seem to have good evidence that a primitive reef ecology and associated lagoon facies occurs as early as the Middle Ordovician.⁶ The interesting lagoon facies of modern reefs (atolls), unlike those of the Paleozoic, are at all times in relatively deep basins with stagnant bottoms, and thus are not subjected to intertidal phenomena. Further, Drewite has not been studied in sufficient quantity or over wide enough areas to determine how it would be affected by slight uplift or depression such as might take place on wide mud flats or broad parma-like areas such as appear to have existed in the Paleozoic seas.

Last December the writer made a preliminary and somewhat hasty trip to the Great Bahama Banks with the hopes that in this region it would be possible to study the Drewite or lagoon facies of the west coast of Andros Island. The Drewite is known to occur here on the surface of wide "mud" flats many miles in extent. Along the shores of Andros the writer hoped to see such structures in the making as have already been observed in certain Paleozoic limestones and dolomites.

⁵ Two papers which summarize the subject are:—"A Preliminary Paper on the Origin and Classification of Intraformational Conglomerates and Breccias," by R. M. Field, *Ottawa Naturalist*, Volume 30, May, June-July, Aug.-Sept., 1916; and, "Autoclastic, Intraformational, Enterolithic, and Desiccation Breccias and Conglomerates, with References to some Australian Occurrences," by W. Howchin, *Trans. Royal Soc., South Australia*, 44, 300-321, 1920.

⁶ Field, R. M., *The Middle Ordovician of Central and South Central Pennsylvania*, this *Journal*, 48, 414-419, 1919.

The expedition was reasonably successful, and a number of phenomena were observed both unsuspected and predicted. Sufficient samples and data were collected for preliminary laboratory studies and Mr. Maurice Black of Trinity College, Cambridge, is now studying this material at Princeton. A second expedition is planned during the spring and summer on which we expect to acquire further data now that we know where to look for it. The great Bahama Bank, or as the writer prefers to call it, the great lagoon of the Bahamas, is roughly in the form of a crescent and extends from the 26th to the 22d parallel. Nowhere is the depth, at low water, over four fathoms and the average depth is probably less than three fathoms. Except for a few small cays of cross-bedded oölite, the waters of the lagoon open freely into the Straits of Florida and the Santaren Channel on the southwest. The few cays on the western margin are located north of the 25th parallel and south of the 23d parallel. The western edge of the lagoon drops off very rapidly from approximately 3 fathoms to over 100 fathoms within a distance of a mile or less. On the east the lagoon is bordered by Andros Island which is approximately 90 miles long and 40 miles wide at its broadest part. This island has an average relief of only a few feet above sea level, except for some low hills of cross-bedded oölite. The west coast of Andros has no reef but the east coast has a fringing reef facing the Tongue of the Ocean, and best developed between High cay and Golding cay.⁷ The total area of the Great Lagoon between the western shore of Andros and the Florida straits is over seven thousand (7,000) square miles. The best descriptions of this region are by Agassiz and Vaughan.^{8, 9}

In the recent expedition to the Bahamas the writer chartered a 60-foot gasoline cruiser at Miami and in spite of the heavy northwest and southwest winds was able, in seven days, to make a traverse from Bimini to Williams Island, off the west coast of Andros. From Bimini to Gun Cay the cruise

⁷ Goldman, M. L., Proportions of Detrital Organic Calcareous Constituents and their Chemical Alteration in a Reef Sand from the Bahamas, Carnegie Inst. of Washington, Publication 344, 37-66, 1926. Dr. Goldman has made an analysis of the "coral sands" on the northeast coast of Andros.

⁸ Agassiz, A., A Reconnaissance of the Bahamas and of the Elevated Reefs of Cuba in the Steam Yacht "Wild Duck," Bull. Mus. Comp. Zool., vol. 26, No. 1, 50-64.

⁹ Vaughan, T. W., Preliminary Remarks on the Geology of the Bahamas with special Reference to the Origin of the Bahaman and Florida Oölites, Carnegie Inst. of Washington, Publication 182, 49-54.

was on the Gulf side of the northern cays which are formed of cross-bedded oölite. All of the cays from North Bimini to South Riding Rocks are formed of the same material, there being no evidence of corals or coral reefs. All the cays are being rapidly eroded, especially on the Gulf side, and appear to be pre-Pleistocene sand dunes. From South Riding Rocks we held a straight course for Williams Island, off the west coast of Andros Island. Several samples of the bottom



Fig. 1. West Coast of Andros Island at low tide. This "mud" flat is composed of practically pure calcium carbonate (Drewite).

deposits and surface waters were taken both going and coming from Williams Island, and we had an excellent opportunity to study the general conditions on the Great Bahama Bank (lagoon) during rough weather. The sea was the color of milk and although we seldom had more than six feet of water under our keel, we did not see the bottom during the entire time that we were at sea. The bottom samples from all stations, except close to the outer bays, contain a high percentage of Drewite but no oörites. In fact the only oörites encountered on the whole trip were in the bottom deposits

close to the cays, from which they were probably derived. There is no evidence to show that oölites are being formed at the present time in the Great Bahama Lagoon. No oölites have developed in the bottom samples since they were collected and preserved in their native sea water. It is interesting to note that so far as the writer has been able to determine, the fine Drewite was in no way affected by the mechanical agitation except to keep it in suspension. This observation seems to be in accord with the phenomena studied in numerous thin sections of Paleozoic limestones (Vaughanite). According to records obtained from the sponge fishermen at Billy and Williams Islands, when the wind died down it would take from five to seven days for the sediment to settle. The sedimentary benthos, such as corals, sponges, etc., would then be completely covered by Drewite but would gradually free themselves from this exceedingly fine precipitate. Thus the organisms would survive for several years in spite of frequent bottom "stir-up." It would be interesting to learn whether or not the sedentary benthos was appreciably destroyed during particularly stormy years. There is evidence to show that the sedentary benthos is able to survive particularly heavy short blows, such as hurricanes. This would seem to throw some light on the peculiar sedimentary and ecological conditions as illustrated in the lower mottled dolomite at Winnipeg and similar formations. The writer was particularly impressed with the fact that while reefs or even "reef societies" are unable to obtain a "foothold" on the Great Bahama Lagoon, in places, there is quite a flourishing bottom fauna which is able to survive long periods of bottom "stir-up." It is perhaps significant that the ecology of this sedimentary benthos is remarkably similar to that of certain limestones and dolomites.

The coasts of Billy and Williams Islands and the west coast of Andros are only a few feet above tide level. During the last severe hurricanes the waters of the lagoon completely flooded the smaller islands and must have inundated a considerable portion of Andros. The surfaces of the smaller islands are everywhere covered with several inches of sediment which appear to have been left by the subsiding waters of the lagoon. This fine calcareous sediment is covered with desiccation fractures for many square miles. These fractures (mud cracks) are both of the limited and unlimited type and in places are being preserved by a filling of relatively coarse fragments of wind-blown shells. The surfaces of the poly-

gons are everywhere relatively flat and quite similar to forms observed in the purer Paleozoic limestones. The shores of the islands are being actively eroded to form from two to four foot cliffs, on the faces of which the writer was delighted to discover abundant evidences of intraformational conglomerates. Along the shores of Billy and Andros Islands these structures are actually being produced in the fine-grained, relatively shell-less, plastic, calcareous muds. Some of these intraformational conglomerates were identical with those already observed in the Paleozoic limestones and dolomites and which we have only been able to reproduce by artificial experiments heretofore. In places the waves were cutting into a stratum of intraformational conglomerates and forming a new bed of intraformational conglomerates with phenoplasts of intraformational conglomerate enclosed in a matrix of Drewite and fresh shell sand. The writer has seen numerous examples of such glomerates in the Paleozoic rocks and believes that they are good evidence of minor unconformities. Indeed it is quite possible that such types of glomerates may represent a well marked physical hiatus within what may have been mapped or described as a single formation. It is becoming increasingly clear that the physical evidence of hiatus, even of period significance, is exceedingly complicated, and much more varied than has been supposed. Where "unconformities" have been postulated by paleontologists in marine limestones and shales, there may be some form of gradational contact shown by change in character of the sediments rather than by a well defined plane of erosion with superjacent conglomerates or reworked soils. The writer believes that intraformational conglomerates within intraformational conglomerates are, when checked by paleontology, exceedingly delicate tests of the stability of a coast line, and as such will prove useful in stratigraphical problems. While simple intraformational conglomerates of a certain type *may* be only the result of intertidal phenomena, the compound type, mentioned above, must represent at least a hiatus of more than diastemic importance, and may even be of period significance. In fact such unconformities are being produced where the sea is cutting into the plastic Cretaceous and Tertiary sediments of the Atlantic Coast at the present time.

Along the west coast of Andros Island lies a great mud flat the surface of which is covered with pure white, dazzling Drewite (Fig. 1). The flat rises very gradually from the

shallow waters of the lagoon and is difficult of approach. We were only able to bring the yacht within a mile of the shore, after we had been churning our way through a regular soup of fine liquid white mud. With a small rowboat we were able to get within an eighth of a mile of the shore, where we had to wade the rest of the distance, sinking into the Drewite at each step, well above our knees. Whether or not this Drewite is of bacterial origin, and if so, whether it is the result of the metabolism of bacteria or of their decay and putrefaction, the writer believes, is still open to question. We are at present making a careful analysis of the stratum immediately underlying the zone of Drewite. This underlying stratum is full of organisms, the metabolism and putrefaction of which may contribute to the formation of the Drewite. It is also possible that the present mud flats are the result of the reworking of older deposits, which form the west coast of Andros Island. But this hypothesis only puts off the question of the origin of the Drewite, for it is becoming increasingly evident that this type of sediment which forms such a relatively high percentage of the deposits on the islands and in the lagoon is not composed of finely ground tests of shells or even microorganisms but is probably a chemical precipitate of either organic or inorganic origin.

SUMMARY.

The west coast of Andros Island and the Great Bahama Bank is an excellent place in which to study the origin of fine-grained calcareous muds because nothing is being contributed from the land either in a solid state or in solution which did not at one time originate in shallow, tropical, marine waters. The Great Bahama Bank probably represents a type of lagoon which was fairly prevalent in Paleozoic times and is unique in that it is relatively shallow and not bordered by true reefs. At the present time the region is humid and wind blown deposits of the arid type are relatively insignificant. An examination of the samples already collected is expected to throw some light on the following problems:

(1) By means of thin sections an attempt is being made to investigate the petrological structures of Drewite in various stages of consolidation. Further study of some of the Paleozoic limestones, intraformational and otherwise, will also be

undertaken to determine whether or not they contain any structures in common.

(2) The bottom samples from the lagoon and the miniature cliffs of Andros are being carefully searched to see if there is any relation between the Drewite and the origin of oölite. So far no *original* oöoliths have been discovered. Several samples are stored in their original sea water to see whether oölites will develop after standing for several months with or without agitation.

(3) A study of the ecology of the "muds" along the shore-flats may indicate to what extent, if at all, the precipitation of CaCO_3 is brought about by plants other than bacteria.

(4) The distillation of the Drewite may throw some light on the source of petroleum.

In the next expedition it is proposed to:

(1) Collect as many core samples as possible from the lagoon to determine, if possible, the relative amounts of Drewite and shelly material. Some of our present samples contain molluscan shells and a fairly high proportion of foraminifera. At present it appears as if these samples represent local and exceptional facies. By means of the core samples we may also be able to determine the effect of "bottom stir-up" on the concentration and lamination of shallow water deposits.

(2) Collect data on the salinity and organic content of the surface waters of the lagoon at different temperatures and during calm and rough weather.

(3) Study the direction of tidal and other currents in an effort to discover the possible source of a constant supply of CaSO_4 .

(4) Study the physical and chemical reactions which presumably take place in the Drewite on the intertidal flats during the hot summer months.

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THE ADSORPTION OF VAPORS.*

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INTRODUCTION.

The sorption of vapors by adsorbents such as silica gel, alumina, and charcoal has been interpreted in recent years mainly by two theories, the Eucken-Polanyi (1)¹ theory of multimolecular layers and the Patrick (2) capillary condensation theory. The mathematical expressions of these theories have been applied to experimental data on adsorption in the literature (1g, h) and to new work (2) and have been found to apply to most data, to which, however, Freundlich's (3a) equation can also be applied. The advantage claimed by the

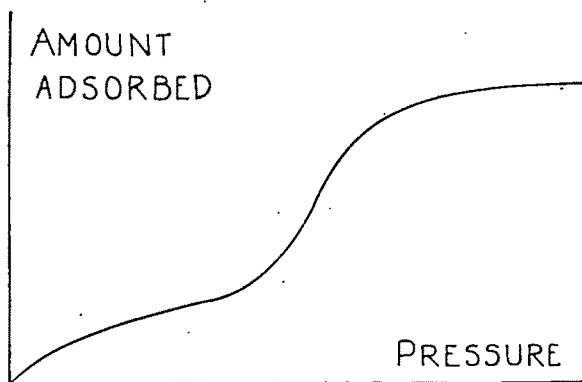


Fig. 1.

other equations is that the isotherms may be calculated at various temperatures from one experimentally determined isotherm, while the simple Freundlich equation applies only at a single temperature. All of the equations fail when applied to a curve like that shown in Fig. 1. This curve represents the sorption isotherms of water on alumina, silica gel, and other adsorbents (4), the sorption of ethyl alcohol and benzol by silica gel (5), or the sorption of methyl alcohol on charcoal (6), alumina, or ferric oxide (7). For this type of curve special hypotheses are necessary to explain their deviation from the equations.

*From a dissertation presented to the Graduate School of Yale University—in June 1927—in candidacy for the degree of Doctor of Philosophy.

¹Numbers refer to references at the end of the paper.

In the present paper an attempt will be made to show that this type of curve is one of those generally possible for the system vapor-adsorbent, and to show the weaknesses of the above mentioned theories in the light of the available experimental data and the modern notions of surface relations.

DISCUSSION.

In a system comprising a solid adsorbent, such as charcoal or silica gel, and a vapor, the mechanisms by which we can imagine the process of sorption to occur are the following:

1. Surface adsorption
 - a. Monomolecular Layers of Langmuir
 - b. Multimolecular Layers of Langmuir (10)
 - c. Multimolecular Layers of Eucken-Polanyi (1)
2. Capillary Condensation (2, 5, 9)
3. Absorption as defined by McBain (3b)

For the purposes of this paper we shall assume the absence of absorption to simplify the matter. In this case equilibrium is reached extremely slowly and is a case which may be assigned to the realm of true solid solution (11).

Surface Adsorption.

Essentially there are two conflicting views on surface adsorption, those of Langmuir and of Eucken-Polanyi. Langmuir believes that adsorption is in reality a type of chemical union between the adsorbate and adsorbent molecules differing only in degree from the type of chemical union represented by Werner's secondary compounds. This state of affairs is represented, in general, by a unimolecular layer of adsorbate molecules at the surface, although it is possible in certain cases that there is enough attraction between this layer and remaining adsorbate molecules to form secondary layers.

Eucken and Polanyi maintain that the process is primarily a compression of the adsorbate at the surface due to surface forces of the adsorbent molecules, a condition resembling that of the earth and its atmosphere (1f).

This controversy narrows down to the same difficulty which arises in the theories of capillarity (8) and which has, as yet, not been solved. It is the question of the range of action of the forces between molecules. The following discussion of

surface adsorption will show many points which are not easily expressed quantitatively and which may be narrowed down to arguments on the law of forces between molecules.

The cause of adsorption may be sought in the tendency of surfaces to decrease their surface energy by the concentration of other molecules at those surfaces (3c). A comparison of the solid-vapor interface with other interfaces such as gas-liquid or liquid-liquid will show us a peculiarity of the former. Gibbs' equation

$$a = - \frac{c}{RT} \frac{d\sigma}{dc}$$

where a is the surface excess or amount adsorbed, c is the concentration, σ is the surface tension and R and T are the gas constant and absolute temperature, respectively, derived thermodynamically for dilute solutions is usually held to apply for adsorption at mobile interfaces. In these cases the difficulty of accurate quantitative proof has been in the measurements of a , the amount adsorbed. For a solid interface this value can be readily measured, but no practical way is known for the measurement of the surface energy of adsorbents.

The distribution and magnitude of this surface energy is dependent upon the nature and extent of the surface. The specific surface of a solid is inversely proportional to the size of the particles. In a very finely divided substance, like charcoal, the specific surface may reach values estimated as high as 150 to 900 square meters (12). The tendency is for a reduction in area to take place, thus decreasing the free energy. Liquids with their mobile interfaces are able to do this and a free liquid assumes the spherical form which has the least area per given volume. A solid can not do this except at higher temperatures where the rigidity of the solid molecules is overcome.

The problem of the surface energy might be simple if it only depended upon the extent and the chemical nature of the surface. It is known, however, and it can be demonstrated experimentally, that the surface energy is greater at the corners and edges than on a plane surface (13a).

The intensity factor in surface energy is dependent upon the chemical nature of the interface. It will depend on what the substance is, for we feel certain that equal areas of different substances do not necessarily adsorb equal numbers of molecules. Further, when we have a given substance, the

intensity will depend upon the interface exposed, i.e. the plane surfaces of a cubic and octahedral sodium chloride crystal do not show the same distribution of sodium and chloride ions. This idea led Langmuir to the formulation of "elementary spaces" capable of retaining a definite number of molecules at saturation (10c).

The nature of the surface will also determine the specificity of adsorption. Carbon in the form of diamond will adsorb methylene blue but not succinic acid, whereas the reverse is true for graphite (14). Further evidences of specificity are shown by evidences of molecular orientation from the temperature coefficients of reaction velocity constants in catalytic processes (13b) and from the crystallization of organic substances on mica (14).

Langmuir (10c) further suggested, as already noted, that the adsorption film was unimolecular in character, basing his deductions upon the adsorption of gases on plane surfaces whose area was known and upon the evidence from his work on insoluble films on water. He did not neglect the possibility of multimolecular films in cases of gases and vapors and derived an expression basing his theory on the assumption that the secondary films were formed by the forces acting between the unimolecular layer and the adsorbate molecules striking the surface. This is in direct conflict with the Polanyi viewpoint of the adsorbed multimolecular layers due to the attractive forces of the solid.

Although adsorption equilibrium represents a dynamic state of affairs, the state of the adsorbate molecules suggests a resemblance to the solid state rather than the liquid or gaseous states in which an equation of state is applicable, as Polanyi assumes.

As previously noted, the question of the range or the law of forces acting between atoms is one for which conclusive evidence has not yet been presented. Experimental work from which conclusions about its magnitude may be drawn are scarce and too little is known about the forces for accurate theoretical calculations, although Einstein and Born (cited by Garner, 14) have estimated the atomic forces falling to one-half at a distance of 0.3 A. U., a fact supporting the unimolecular film.

Besides Langmuir's work which has been extended by N. K. Adams for films on water, the following cases of unimolecular films seem definitely established:

1. The adsorption of toluene vapor at low pressures by Pyrex glass at 0° (15) and recently on ordinary glass at varying temperatures (16).

2. The adsorption of water, methyl acetate, and benzol vapors on mercury. The amount adsorbed up to the vapor pressure of the pure liquid never exceeded the amount necessary to form a unimolecular film and was calculated by the use of Gibbs' equation (17).

3. The adsorption of dyes by lead sulphate crystals whose area had been definitely determined using radioactive indicators (18).

The existence of multimolecular layers on surfaces has been claimed by various workers (19). Their work is vitiated by various experimental errors. The recent work of Frazer, Patrick and Smith (16) especially shows that the majority of the others are definitely wrong.

The evidence presented is against the Polanyi mechanism of multimolecular layers. Langmuir's theory gives a good picture of the adsorption process; his equations are not readily applicable to vapor systems due to the complicating factors of capillary adsorption, which he recognized, and to our present ignorance in measuring the independent variables, such as extent of surface, elementary spaces, etc. Surface adsorption may be characterized as unimolecular or multimolecular from the Langmuir standpoint, specific, and for a given adsorbent dependent upon the chemical nature of the adsorbate. The amount of adsorption will depend upon the specific surface and the nature of the surface.

A. S. Coolidge (20), who is a supporter of the Polanyi theory in a modified form, has suggested that the form of the curve obtained similar to Fig. 1 is a peculiarity of polar liquids. Besides his own evidence he offers that of Anderson (5). In his paper he cites only Anderson's water-silica gel curve, forgetting that Anderson also had the same type of curve for benzol and ethyl alcohol on silica gel. Certainly benzol is a nonpolar liquid (24) and since it is also capable of giving isotherms similar to Fig. 1, Coolidge's hypothesis must be regarded as inadequate.

Capillary Condensation and the Form of the Isotherm.

In the adsorption of vapors, surface adsorption plays a smaller rôle than capillary condensation when a comparison of

the amounts taken up are made (4d). The surface effect is most noticable at low pressures but saturation of the surface may not occur completely before capillary condensation occurs. The two overlap in many cases so that they can not be separated. Curves of this overlapping type usually fit the Freundlich isotherm, and the interpretation of the mechanism has led to the conflicting views. Polanyi (1f), Hällstrom (7b), and Coolidge (20) describe it as a surface compression while Patrick claims capillary condensation as the explanation. Zsigmondy and others (9) have taken both into consideration and consider adsorption as a combination of surface adsorption and capillary condensation.

The form of the adsorption isotherm of a vapor, if Zsigmondy's views are accepted, will depend upon the extent of the adsorption (surface effect) and the range of capillary condensation. The latter is due to the lowering of the vapor pressure of a liquid with highly concave surfaces. Anderson (5) derived the following expression for cylindrical capillaries at constant temperature:

$$\log p_0/p = \frac{0.8686\sigma\Delta}{dp_0r}$$

where the letters have the following significance:

- p_0 = vapor pressure of the liquid at a plane surface
- p = vapor pressure of the liquid in the capillaries
- σ = surface tension of the liquid in dynes/cm.
- Δ = saturated vapor density
- d = density of the liquid
- r = radius of the capillaries

The equation shows that the pressure at which condensation occurs is not only dependent upon the radius of the capillaries but also upon the physical properties of the liquid. The amount adsorbed is the other variable determining the course of the capillary condensation and is determined by the available capillary volume and its distribution.

Adsorbents of the type of alumina present on a greatly magnified scale a picture reminiscent of a sponge. The application of the ultramicroscope by Zsigmondy to the study of rigid and elastic gels has led to the recognition of their structure. At present a gel is considered as a two phase structure. The discontinuous phase is made up of fibrous micelles, in some cases crystalline, entraining the continuous liquid phase.

The rigid gels which are used as adsorbents are characterized by very short thick fibres in contrast to the elastic gels which have long, narrow fibres. Upon the drying of the gel formed either by gelation or precipitation as a gelatinous precipitate there is a contraction in volume decreasing the sizes of the capillaries formed by the network of fibres. After constant volume is reached, heating of the gel removes adsorbed water and water held in solid solution, though only completely at higher temperatures.

There is no way of predicting the volume, form, and geometric dimensions of the pores, and no way available for determining the distribution of the various kinds in any adsorbent. Even in the determination (21) of the capillary volume, discrepancies are found by the use of various liquids. Our knowledge of these capillaries is limited to an approximate estimate of the volume and the realization that adsorbents with capillaries of all possible dimensions and shapes are possible and that it would only be some very special gel or accidental circumstances that would yield an adsorbent with one kind of capillaries, like the silica gel with conical capillaries, assumed by Patrick.

An interesting problem is the question of the lower limit in size of the capillary pore capable of retaining molecules in the liquid state. The equation cited above being derived thermodynamically gives no clue as to the limit of its application. But application at very low pressures gives values of the radii of the order of magnitude of the radii of atoms determined by X-rays or calculated from the physical constants of gases. For example, at 25° and 1 mm. pressure, water and benzol would be in equilibrium with vapor in capillaries of 3.21 and 4.25 A. U., respectively. The sizes of the molecules given by Jeans (22) are 2.29 and 3.75 respectively. It would appear, therefore, that at very low pressure, adsorption cannot be capillary in character, if Anderson's formula is to hold.

Patrick in his work (2) on the adsorption of vapors by silica gel has ascribed the phenomenon to capillary condensation and has used the following equation *empirically* obtained from Freundlich's equation:

$$v/m = K \left(\frac{p\sigma}{p_0} \right)^{1/n}$$

where

v/m = volume of the adsorbate as liquid per unit adsorbent
 p = pressure of vapor in equilibrium with adsorbed liquid
 p_0 = vapor pressure of liquid at plane surface
 σ = surface tension of the adsorbate
 K and $1/n$ are constants

This particular equation is supposed to have the advantage of applying at all temperatures for any vapor with an adsorbent like silica gel. Fig. 2 shows Patrick's isotherms of

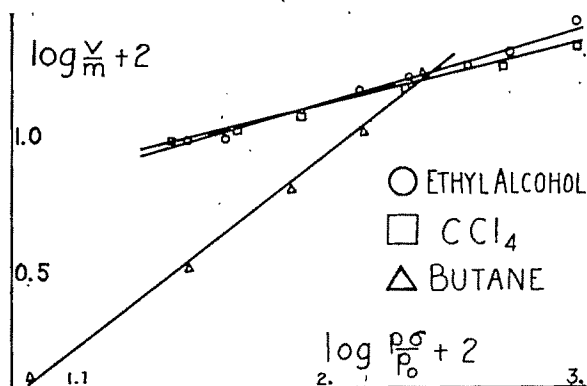


Fig. 2.

ethyl alcohol (2d), carbon tetrachloride (2d), and butane (2b) on silica gel of 3.57% water content. In this case the $\log v/m$ was plotted against the $\log \sigma p/p_0$, the corresponding pressure. This, as Patrick has pointed out, should give a straight line which coincides for every adsorbate. This is clearly not the case, and that it need not be the case can be shown.

What form of isotherm results if an ideal adsorbent of the simplest structure is assumed? Suppose for our case one with perfectly cylindrical capillaries of radius r is the model adsorbent. (Dehydrated chabazite and other zeolites may be good examples of this type.) Absorption will be considered as absent and the two processes which will be considered are adsorption and capillary condensation. The adsorption curve will depend upon the specific interaction between the surface adsorbent molecules and the adsorbate molecules at the temperature assumed. The point at which the capillary condensation occurs will be determined by the value of r and the physical properties of the liquid, using Anderson's equation

for the calculation of the pressure for any given radius. A combination of the two will be the ideal curve. Table 2 gives the calculations for water, benzol, methyl alcohol, and diethyl amine based on the data given in Table 1. The physical constants were obtained from Landolt-Bernstein Tables (5th ed.) and the Critical Tables. The vapor pressure curve of diethyl amine was calculated from an equation using the Hildebrand modification of Trouton's rule in the Clapeyron equation. The equation was based on the data for water and required only one vapor pressure determination for diethyl amine. The saturated vapor densities were calculated by means of the ideal gas law. The letters have the same significance as heretofore used.

TABLE 1.

Substance	p_0 (mm.Hg)	$t = 25^\circ$ d (g/cc)	Δ (g/cc)	σ (dynes/cm)
H ₂ O	23.756	.997	.00002302	69.75
CH ₃ OH	122.2	.787	.000209	22.45
C ₆ H ₆	94.4	.874	.00052	27.40
(C ₂ H ₅) ₂ NH	139.4	.71	.000548	18.3

TABLE 2.

r in $\mu\mu$	100	75	50	25	10	5	3	2	1
p/p_0 H ₂ O	.991	.987	.98	.961	.903	.816	.712	.601	.362
p/p_0 CH ₃ OH ..	.995	.992	.986	.973	.928	.862	.780	.690	.473
p/p_0 C ₆ H ₆	.981	.975	.962	.926	.824	.679	.526	.381	.145
p/p_0 (C ₂ H ₅) ₂ NH	.976		.970		.858	.738			.219

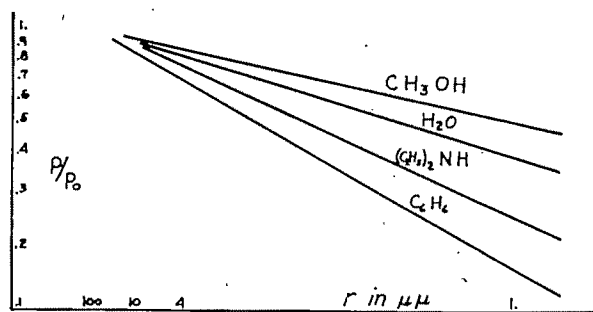


Fig. 3.

Fig. 3 shows these results plotting the radius in $\mu\mu$ against the relative pressure using a reciprocal scale for r and a logarithmic scale for p/p_0 so that a straight line results.

Using these tables the ideal curves obtained for our ideal adsorbent plotting the volumes of the liquids adsorbed per

unit adsorbent against the relative pressure are shown for two values of r in Fig. 4. The curves show that with decreasing radius the pressure at which condensation occurs becomes smaller and decreases the extent of the curve where only surface adsorption is taking place. With capillaries of varying sizes the curve may lose its inflection point much like the curves for most organic vapors on charcoal. The inflection point may, however, be found in some cases at low pressures (23).

The combination of surface adsorption and capillary condensation applied to the adsorption of vapors by porous substances gives an answer to what is supposed to be an anomalous

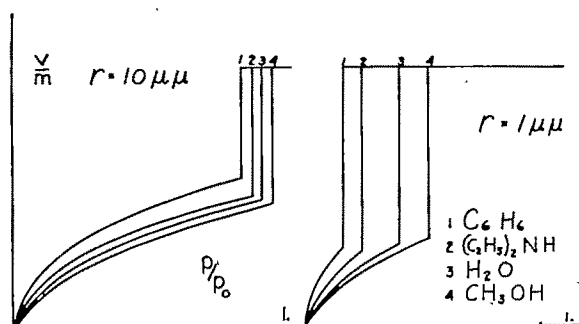


Fig. 4.

behavior on the part of water by several investigators, Coolidge (20b), Patrick (2d), and Berl and Andress (6a). Each found that their curves for water resembled our ideal curve while other vapors such as benzol, ether, butane, carbon tetrachloride, and sulphur dioxide have been found to give curves of the exponential type.

Patrick's explanation of the form of the water isotherm is based on the increased viscosity of water under pressure below 35 degrees. The pressure is supplied by the capillary forces which act upon the water in the pores. At very low pressures the forces are large, hence the water very viscous and equilibrium may not be reached. This explanation will not suffice, however, since our ideal type of curve has been approached by Anderson, Gustaver, and Bachman by decreasing the vapor pressure, that is going from higher volumes adsorbed to lower. Also it must not be forgotten that the same type of curve has been obtained for other substances whose viscosity does not increase with pressure.

The application of the ideal curve for real adsorbents is made difficult by the variable capillary structure. Anderson has found the ideal curve approximated quite closely in the adsorption of ethyl alcohol, water, and benzol by silica gel. But all types of intermediate curves are found down to the curve representing the Freundlich and Patrick equations. Until the problem of measuring the true variables is solved, there will be no satisfactory equation to represent all types of vapor adsorption.

CONCLUSION.

The Eucken-Polanyi and Patrick theories of vapor adsorption and Coolidge's theory of the form of curve ascribable to polar liquids have been criticized.

The qualitative mechanisms of vapor adsorption by silica gel, alumina, charcoal, etc., is pictured as by Zsigmondy and others as a mixture of surface adsorption according to Langmuir's views and capillary condensation of the vapor. The two may be sharply separated or may overlap completely so that they may not be distinguishable. The type of curve depends not only upon the physical properties of the adsorbate but also upon the capillary structure of the adsorbent.

I wish at this time to express my thanks and appreciation to Professors Foote and Saxton for the assistance which they have rendered to me in this paper.

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DISCUSSION AND COMMUNICATIONS.

THE TRIASSIC OF CONNECTICUT.

A recent publication by J. K. Roberts, entitled "The Geology of the Virginia Triassic,"¹ presents a stratigraphic and structural study of the Triassic areas in Virginia. A commendable part of Mr. Roberts' work lies in his application of modern methods in studying the Triassic sediments. The next large advance in the study of other eastern Triassic formations must come from even more intensive use of such methods. After these careful studies are made for each of the unit areas, from Nova Scotia to North Carolina, we shall be in a position to make more confident generalizations regarding the eastern Triassic than are possible at present.

Unfortunately Roberts attempts to extrapolate from his limited local basins to others far removed; and very obviously he has not seen some of the areas for which he offers confident interpretations. For example, he not only makes sweeping statements regarding the stratigraphy and structure of the Connecticut Valley, but he expresses erroneous views in a diagram. Geologists who have seen the Connecticut section will not require any discussion of the matter; but as others may think that Roberts' figure represents a plausible conclusion based on actual field study, a brief correction will be presented.

In the Virginia areas Roberts recognizes three principal sedimentary units: the "border" conglomerates, the Manassas sandstone, and the Bull Run shales. He correlates the conglomerates found on opposite sides of the basin, and concludes that these coarse deposits originally extended continuously across the basin, which was never much wider than the present Triassic area. As sedimentation proceeded, deposits of sand built up within the basin, grading into and partly covering the coarse gravels; and finally muds accumulated in the axial part of the trough, grading outward into the sands. Applying this conception to the Connecticut basin, among others, he presents the following figure to represent the Connecticut sediments as they were deposited.

This diagram is based on a supposed recognition, in the Connecticut section given by Davis, of three general units similar to those in Virginia. This section, from Davis' first general paper on the Connecticut Valley,² is as follows:

¹ Charlottesville, Va., 1928.

² Davis, W. M., The Structure of the Triassic Formation of the Connecticut Valley: 7th Ann. Rept., U. S. Geol. Survey, 461-490, 1888.

	Feet
(6) Conglomerates, sandstones and shales	2,000- 3,000
Posterior trap overflow	50- 150
(5) Sandstones and shales	300- 500
Main trap flow	300- 500
(4) Shales with thin limestone	100- 300
Anterior trap flow	50- 150
(3) Shales	500- 500
(2) Shales, sandstones and conglomerates	3,000- 3,000
Intrusive trap sheet	200- 400
(1) Sandstones and conglomerates	500- 2,000
Total	7,000-10,500

(The "trap overflows" are buried basaltic lavas)

Students of the Connecticut Triassic will wonder why Roberts omits the important lava flows from his diagram, and why he selected this older section instead of the measurements given by

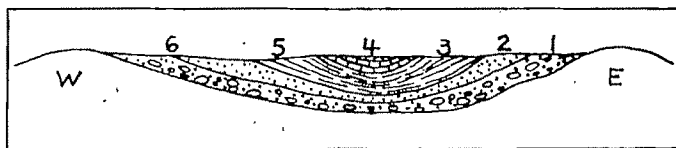


Fig. 1. Cross section of the Connecticut Triassic, according to J. K. Roberts, representing his attempted correlation of the stratigraphic units defined by W. M. Davis. The numbers correspond to the units in Davis' section. See Fig. 2 for correct relation of these units. Roberts represents No. 4 with common symbol for limestone. In fact it is sandy shale with a single layer of fresh water limestone in some localities:

Davis ten years later, based on more extended study and maturer judgment. This later section recognizes the same general divisions, but estimates the total thickness at 10,500 to 13,100 feet.³ The buried lavas are the most important consideration. Lacking any direct acquaintance with the Connecticut section, Roberts could not know that these lava units and the intervening sedimentary formations are perfectly definite and unmistakable horizons, which make it possible to determine the general stratigraphy and structure of Central Connecticut with considerable accuracy. No guess work is required in defining the principal units in this stratigraphic section. The work of Davis has been checked critically by several workers, including the present writer. If there were ever any doubts about the succession in the eastern half of the basin (and the evidence there has always been reasonably definite), they have been completely dispelled by a series of tunnels and cuts in a new water aqueduct, which has exposed a nearly continuous section

³ Davis, W. M., *The Triassic Formation of Connecticut*: 18th Ann. Rept., U. S. Geol. Survey, 28-29, 1898.

reaching from the lower or "anterior" trap sheet to the eastern border. This artificial section, which has been studied carefully, establishes the succession given by Davis and vindicates his estimates of thickness in this upper portion of the Connecticut Triassic.

The following section by Barrell shows the stratigraphy and structure just north of Meriden. The numerous faults repre-

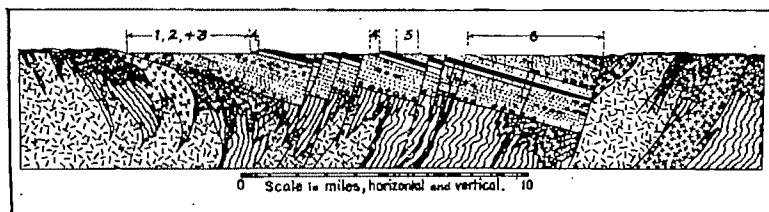


Fig. 2. Barrell's section across the Connecticut Triassic north of Meriden (see Fig. 4). The three buried lava flows, as well as minor intrusive bodies, shown in solid black. Old crystalline rocks shown with various patterns. Numbers correspond to units in Davis' section.

sented in this section are indicated plainly at the surface by repetition and offsetting of the lava sheets, and displacements of the faults can be calculated with reasonable accuracy. A comparison of this figure with Fig. 1 shows the fundamental error in Roberts' conception. In each figure the numbers correspond to those in the section from Davis. The unit 6 is on the *east* side of the valley, and unmistakably above the upper lava flow; units 1, 2, and 3 lie in that order between the western margin and the lower lava sheet, all dipping consistently eastward. The comparison needs no further comment.

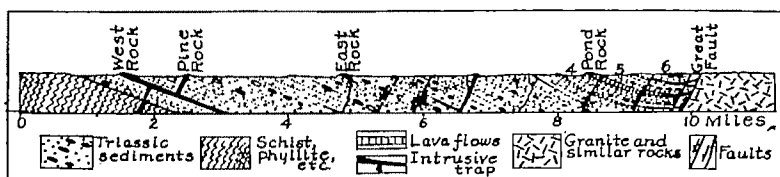


Fig. 3. Cross section of the Triassic near New Haven. Intrusive and extrusive trap shown by separate conventions. Apparent thickness of lower series (1, 2, and 3 of Davis' section) increased by strike faulting.

Fig. 3 is a section constructed by the writer for the southern part of the Triassic area. As the marginal fault on the east cuts toward the southwest, the width of the area is greatly reduced in this section, and only a moderate thickness of the highest formation (No. 6) is preserved. Except for the great boundary frac-

ture, there are no faults with important displacement in the eastern part of this southern section. It will be noticed that the width of outcrop of the "lower series," between the lava sheets and the western margin, is considerably greater than in the section north of Meriden. This difference appears also in map, Fig. 4. A part of the explanation lies in a series of great oblique faults which offset the trap ridges and the Triassic margins. In the opinion of the writer, there is also considerable strike faulting between

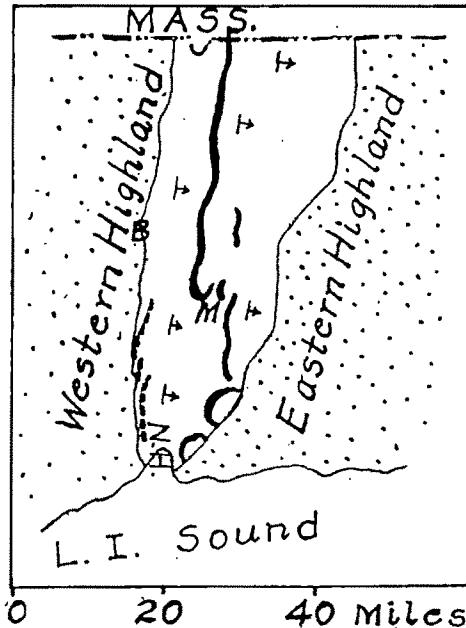


Fig. 4. Sketch map of Connecticut Triassic area. Outcrop of the middle ("main") lava sheet in solid black. B, Bristol; M, Meriden; N. H., New Haven. Note increased width of lower series south of Meriden, and of upper series to north. Faults omitted. Outcrop of intrusive sheet near base of sediments is shown by heavy dots.

Meriden and New Haven. The net effect is duplication of beds in this stretch, to make the apparent thickness of sediments below the lava sheets almost twice the true thickness. North of Meriden, however, there is no indication of large duplication in the lower series. In fact there is even some subtraction from the true thickness by marginal faults dipping eastward, especially in the vicinity of Bristol; and on any reasonable basis the thickness of the lower series is at least 6,000 feet.

Roberts emphasizes the effect of faulting in magnifying the apparent thickness of the Triassic, and of course other students

have given proper attention to this factor. It is apparent, from Roberts' discussion and structure sections, that the Virginia areas contain no infallible horizon markers to aid in quantitative solution of the faults. In this respect the Connecticut section is far more favorable. It is established that the upper series in the section, including the buried lavas, measures more than 6,000 feet, and in the northern part of the state, where exact measurement of the upper conglomeratic member has not been practicable, probably the thickness is considerably more. Thus the minimum thickness of the Connecticut Triassic is certainly in excess of 12,000 feet. Consideration of the lava flows throws out any suggestion that the upper series did not originally extend westward over the lower. These great basaltic sheets are remarkably uniform in thickness along the strike, throughout the length of the state; and as they now have the eastward dip common to the beveled sedimentary formations both below and above, it is certain that the lavas and the sediments interbedded with them once extended much farther westward. In the writer's opinion, there is a very strong case for the view that the original western limit of the Connecticut Triassic was far west of the present margin.

With reference to the conditions of deposition in the Triassic Roberts says: "From all indications there must have been lagoons in the Connecticut area and not such extreme continental conditions as existed farther south." It is surprising that he seeks to discard stratigraphic and structural conclusions that have been established by cumulative evidence, and at the same time resurrects a notion that has long been obsolete. The early workers described the Triassic deposits in the Connecticut trough as "estuarine" or "lagunal." That interpretation was in keeping with the philosophy of the time, which associated every large body of sediments with the sea. All of the evidence indicates that the Connecticut sediments are strictly continental. The deposits themselves testify to piedmont slopes, floodplains, and local floodplain lakes or swamps: there are included fossils of dinosaurs, fresh-water fishes, and typical land plants; and there is not the slightest indication of lagoons or other features related to the sea.

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GRAVITY IN WESTERN CANADA.

For several years past it has not been necessary to publish data to prove that isostasy exists in the crust of the earth. The principle of isostasy has been accepted by nearly all serious students of the earth, but it is rather pleasant to the isostasist to have

substantiating information come to hand from time to time. The latest contribution, and a most important and valuable one, is from the pen of A. H. Miller, a member of the staff of the Dominion Observatory at Ottawa.¹ In this paper he gives detailed information for 69 gravity stations established in western Canada, at which observations were made with the standard half-second apparatus. Part of the work was done under the general direction of the late Dr. Otto Klotz, while the greater part was done since Dr. R. Meldrum Stewart became Director of that Observatory. Geophysics has been enriched by the broad vision shown by these two officials in attacking an important problem.

Miller's paper shows the gravity anomalies reduced by the isostatic method, with a depth of compensation of 113.7 kilometers. The formula used to obtain the value of gravity at sea level for any latitude is the one derived by the reviewer which is

$$\gamma_0 = 978.039 (1 + .005294 \sin^2 \phi - .000007 \sin^2 2\phi)$$

The stations are divided by Miller into five groups, according to political sub-divisions of Canada. In Manitoba there are nine stations and the anomalies, with and without regard to sign, are $+.011$ and $.016$ dyne. There are nine stations in Saskatchewan and the anomalies, with and without regard to sign, are $+.020$ and $.020$. There is no station in this group with a negative sign, although one station has an anomaly of only $+.001$. In Alberta there are 18 stations for which the anomalies, with and without regard to sign, are $+.004$ and $.010$. For that group there are five stations with negative sign, and one has a value of zero. The largest group is in British Columbia which numbers 27 stations. Here the average anomalies, with and without regard to sign, are $+.003$ and $.031$. The smallest group of stations is in the Northwest Territories, being six in number. Here the average anomalies, with and without regard to sign, are $+.004$ and $.009$. In this group the stations are evenly divided between the two signs.

If all of the stations are considered as a single group, the mean anomalies with and without regard to sign are $+.006$ and $.013$. The average anomaly, without regard to sign, is only 65% as large as the one for the United States. There is only one group of stations, that in Saskatchewan, where the mean anomaly without regard to sign is over $.016$. Two have averages of $.013$ and one has only $.010$. Of 69 stations, only seven have anomalies greater than $.030$ and only two are greater than $.040$. The maximum anomaly is at Victoria and is $+.054$.

It is rather remarkable that the largest two anomalies which are positive are near the sea coast. One is at Victoria, with an elevation of 219 feet, and the other is at Union Bay, with an eleva-

¹Miller, A. H., Gravity in Western Canada, Trans. Royal Soc. Canada, 21, Sec. IV, 175-187, 1927.

tion of only 10 feet. It is not necessary to give all of the details of the stations in this review, but the general conclusion may be reached that the anomalies are very small as compared with what they would be if the topography around the stations were not isostatically compensated. There are 43 stations involved which have elevations above 1,000 feet and 23 have elevations of 2,000 feet or more, while 11 stations have elevations greater than 3,000 feet. The maximum elevation is at Paradise Mine, in British Columbia, 7,470 feet, and the anomaly at that station is $-.008$. Since an anomaly of $.001$ may be considered as having been caused by a deficiency or excess of 30 feet of rock, it is evident that if the topography in the vicinity of Paradise Mine had not been compensated the anomaly would be of the order of $.250$ dyne. This is 30 times what the anomaly was found to be.

Miller makes the very significant statement that "It is characteristic of large anomalies that they do not persist over large areas. This is well illustrated by the variation of the anomalies over the Puget Sound district in the United States, . . .". He calls attention to the fact that, at a distance of 20 miles across the Strait of San Juan de Fuca, there is a change from the negative anomaly of $-.008$ at Port Angeles to the largest anomaly known in Canada, $+.054$ at Victoria. Miller argues that the causes of these anomalies are local variations from normal density near the stations. He states that a determination of the densities of some samples of rock exposed near Victoria station showed that they averaged 2.81 . This is much in excess of the normal value of surface rocks, 2.67 , used in the isostatic reduction.

It may be of interest to call attention to the fact that the gravity anomalies at stations of the Coast and Geodetic Survey established in southeastern Alaska along the coast have rather large anomalies. It is possible that the same kind of formation as is found in the vicinity of Victoria may be present in the southeastern Alaska region.

Miller made two determinations of the depth of compensation from the data he used in his paper. One of these was made by the method of least squares for the nine stations in the Mackenzie River basin and the depth obtained was 91 kilometers. He made another determination from the results of 20 stations, three in the Rocky Mountains in Alberta, and the remaining 17 in British Columbia. This value was obtained graphically and, while no definite figure is given for the depth, a reading of the diagram indicates that it is about 98 kilometers. These values of Miller's, obtained in latitudes higher than in the United States, agree very well with the value of 95 kilometers, obtained from the gravity observations alone in this country.

The student of the earth and especially the isostasist, cannot but feel grateful to Mr. Miller and the Director of the Dominion

Observatory for the splendid work in gravity and isostasy that has been done in Canada. It is rather noteworthy that most of the stations involved in Mr. Miller's latest study are in a very rugged part of the continent of North America and that the isostatic condition there seems to be perfect within a very small percentage. The results clearly indicate that there is no piling up of material under stresses that would tend to disrupt the crust of the earth. All of the evidence set forth by the isostasists seems to indicate a lack of great forces of a horizontal nature in the earth's crust. This would lead to the conclusion that changes of elevation must be due to vertically acting forces with horizontal movements as merely incidental to the vertical ones.

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THE CONTINENTAL DISPLACEMENT HYPOTHESIS
AS VIEWED BY DU TOIT.

Ever since the return home, some years ago, of R. A. Daly and F. E. Wright from their geological field studies in South Africa, we have heard that Du Toit, the most enthusiastic supporter of the Wegener displacement hypothesis, would visit South America and give us his observations on the similarities between his own land and that continent. Under a grant from the Carnegie Institution of Washington, Du Toit has spent five months travelling widely in Brazil, Uruguay, and Argentina, always with the best guidance that the local geologists could give him, and now we have his results.¹

The greatest value of the book lies in Du Toit's clearly presented and detailed descriptions of the geology he saw, plus the best information taken out of the literature of South America; and likewise in his views regarding the intercontinental correlations with South Africa, with which he is of course most familiar. These correlations are, however, those of a field worker, a geologist depending almost wholly on the physical evidence, and one who shows that he has but little insight into, and less faith in, paleontology. Indeed, he actually goes so far as to say that fossils are incompetent to solve the correlations demanded. This is the greatest weakness of the book, met with in many places, and finally toward the close of the discussion we read: "*Geological evidence almost entirely* [italics his] must decide the probability of this hypothesis, for those arguments based upon zoö-distribution are

¹ Du Toit, A. L., A geological comparison of South America with South Africa; with a paleontological contribution by F. R. Cowper Reed; Publication 381, Carnegie Institution of Washington, 1927.

incompetent to do so" (p. 118). Curiously, whenever the fossils agree with his conclusions he uses them, although to him all Permian fossils are clearly of Upper Carboniferous age.

In Section F, The Southern Pre-Cordilleran Region (pp. 27-55), Du Toit discusses the Paganzo system, and these pages give a true insight into the methods that control his subsequent correlations. First, he discusses the glacial beds of San Juan and Jachal, and we learn that unconformably overlying the older Paleozoic formations appear three tillite zones that are interbedded with continental strata having plants. He says: "There can not be the slightest doubt that the sequence is a normal upward one . . . and is embracing Paganzo beds only. Great weight, therefore, must be attached to this section, since it provides us with the key to the Permo-Carboniferous stratigraphy of a very wide region in the pre-Cordillera" (p. 31). We will accept it as such, but not at all as regards his interpretations; rather will we follow Keidel, who has seen more of these strata and their fossils than any other worker, and whose correlations, curiously, Du Toit rejects.

Above the lowest tillites, which unconformably overlie much older formations, there soon appear strata having the Culm (= Mississippian) flora with *Rhacopteris* in several species and *Cardiopteris elegans*. At another locality, and evidently in the same formation of Culm time, either Bodenbender or Kurtz got *Rhacopteris inequilatera ovata*, *Archeopteris argentinae*, *Cardiopteris elegans*, *Botrychiopsis weissiana*, *Asterocalamites scrobiculatus*, *Lepidodendron*, etc.

Above this first and oldest glacial zone and flora occurs the second tillite, which he says again "is a perfectly conformable one" with the older series (p. 31); and in strata a little higher occurs the *Glossopteris* flora. As Du Toit saw no unconformity, he holds that there can be no time break in the sequence, though he shows plainly that the lower tillites and associated strata having Lower Carboniferous plants are rather limited in distribution, and that the higher or second tillite with its much younger plant beds is in other places seen to be an overlapping series with a geographic distribution ever so much greater. However, while he sees this possibility of overlap (pp. 37, 39), yet he rejects it, coming to this conclusion: "The overshadowing feature of the sections . . . is the direct evidence that they furnish upon the position of the plant-bearing horizons in relation to the glacials, at the same time proving the close association of European Carboniferous plant forms with members of the *Glossopteris* flora" (p. 32). Now, what are the facts in regard to the strata with their entombed floras in this area of the pre-Cordillera? So far as the writer sees, the two floras in their occurrence are not mixed with one another here or elsewhere (though some field collectors have mixed them), but in certain places follow one another in what appears to be an unbroken sequence, but which the fossils show must be broken by

a disconformity of long time duration. Du Toit places a fairly correct time value on the Rhacopteris flora when he says it is of Carboniferous age, but whether of the Lower or Upper series he does not state. As to the meaning of the plants in the Glossopteris-bearing strata he goes entirely astray and we get this very erroneous verdict: "It might be remarked at the outset that the majority of the members of the Glossopteris flora are of *little or no value* [the italics are his] in establishing the *absolute age* of the beds. Recent work has been showing more and more that certain genera and species thereof had a long range in time and these sections in Argentina are of immense importance, therefore, in demonstrating that *Gangamopteris cyclopteroides*, *Glossopteris browniana*, and *Cordaite hislopi* extend back well into the Carboniferous, as also appears to be the case in New South Wales" (p. 39). None of these statements is true. In regard to the last named region, the writer has discussed it at length in a paper that will appear this year in the *Bulletin* of the Geological Society of America,² with the conclusion that the Rhacopteris flora of Australia is clearly of Lower Carboniferous or Culm time (and in this the writer has the backing of David White). On the other hand, no one has shown that any of the essential elements of the Glossopteris flora occur in strata beneath the Middle Permian. It is, however, well known that many of its species have a long upward range. What Du Toit can not see is that between the Culm and Glossopteris floras lie the various floras of the Upper Carboniferous and the Gigantopteris flora of the early Permian, all of which had their day before the Glossopteris one made its appearance. It is the time duration of these floras that illustrates the length of the break, the disconformity that Du Toit fails to see in what he thinks is a "normal upward" sequence. Many a good geologist not familiar with fossils or failing to collect them has walked over similar breaks of even greater duration without seeing them, but the reason why Du Toit goes wrong lies in the fact that he persistently refuses to evaluate properly the Glossopteris flora, an evaluation that must be obtained from a world study of the Upper Carboniferous and Permian floras, checked into the sequence of the marine faunas. In the present case, we must also recognize the very little known fact that there was in Argentina, at the time the Rhacopteris flora was flourishing, local glaciation in the Lower Carboniferous (= Mississippian system), or in Keidel's Jejenes series, which is 165 meters thick. (It is

² The present review is the second article by the writer opposing the hypothesis of continental displacement. The first, and longer one forms a chapter in "The Theory of Continental Drift," published by the American Association of Petroleum Geologists. The paper to be published this year by the Geological Society of America bears the title "A Review of the Late Paleozoic Formations and Faunas, with Special Reference to the Ice-age of Middle Permian Time."

interesting here to note that the Caney conglomerates = "ice-borne material" of Oklahoma are of the same general age.) Then in the higher strata of Middle Permian time came the basal tillites with the *Glossopteris* flora, followed by a third and thin zone of local glacial materials.

Going north from San Juan to Barreal, some of the Permian fresh-water beds change to marine and contain an interesting invertebrate fauna in two zones separated by 150 meters of strata, described by Reed. In this region the Permian with its tillites rests directly and unconformably upon the glaciated floor of the older Paleozoic formations. Here there are no Lower Carboniferous strata at all. It is therefore curious to see that first Stappenbeck and now Reed and Du Toit say that "these Barreal faunas can, without hesitation, be ascribed to the Carboniferous and probably to the base of the Upper Carboniferous. The tillite should belong, then, to about the border-line between the Moscovian and the Uralian" (p. 35). Now let us see what this fauna from two zones above the tillite shows. Both zones have, according to the reviewer, typical marine Permian assemblages which, when compared with those of the Salt Range and the Himalayas of India, seem to link best with the *Upper Permian* ones. Reed describes thirty-six species, but ten of them are so poorly preserved as to have no value in age determination, and seventeen more have, to the writer's knowledge, no direct correlating value. This, then, leaves nine species which are, to him, clearly of Permian time. These are as follows: *Productus curvirostris barrealensis*, *Marginitifera* cf. *echinata*, *M. spinulo-costata peregrina*, *Spirifer wynnei argentina*, *S. saltensis*, *S. barrealensis*, *S. mexicanus neotropicus*, *Spiriferina zewanensis*, and *Pleurotomaria advena*. Reed, like Du Toit, is governed by the long ranging species, and the Upper Carboniferous is notorious for such enduring forms, many of which persist into the Permian. It is, however, not the long-ranging species that determine limited geologic time, but the short-lived forms, and in the present instance especially, the above mentioned three species of *Spirifers*.

Then Du Toit discusses what should be embraced in the whole of the Paganzo system, which, he says, is the representative of the Karroo of South Africa. The former includes at least four and probably five stages, resting unconformably on the older Paleozoic series, or on yet older crystallines, and in turn is overlain by the Cretaceous or Cenozoic. Stage I, from 150 to 300 meters thick, embraces not only the Lower Carboniferous tillites and flora, but also the *Glossopteris* flora and tillites of the Permian. Stage II, 300-500 meters thick, has no fossils, and yet is referred to the Permian. Stage III, 300-500 and even 900 meters thick, has some marine Triassic with fossils, but what part of this period is not worked out; during the early part of this stage occurred the making of the Gondwanides, and in places there is, accordingly,

an angular unconformity. Stage IV, 400-500 meters thick, has the Thinnfeldia flora and is of Rhaetic or late Triassic time. Finally, Stage V, "with complete conformity," follows with a thickness of 400-500 meters, and may be of Jurassic age. In all of this it is apparent that a "system" is to Du Toit something quite different from that of orthodox stratigraphers, and that he is treating of systems as defined by South African geologists. But of what use in correlation can such a "system" be—one that has formations of any age from Mississippian to latest Triassic and possibly even Jurassic, and in addition, has a time of mountain making? All the use it can serve in the present connection is to show that the Paganzo, as defined by Du Toit, is equal to the Karroo, and yet the former contains two marine horizons and an older flora never seen in the South African "system." It is a very poor fit at best, and shows different, unrelated earth movements in the two continents, while the South African strata are rich in a highly varied amphibian and reptilian fauna that is completely absent in South America.

In the matter of Du Toit's correlations, we find on page 56 the following amazing statement. He is reciting something of the Upper Carboniferous marine fauna of the high plateau of Bolivia, and says it "is that of the Uralian of the Urals, Salt Range of India, and Guadalupian of New Mexico." The correlation in regard to the area first named is about correct, but the second one is certainly of Upper Permian time, and the last named region has both the Lower and Upper Permian and, what is most important in the present connection, has beneath them the equivalent of the Uralian faunas. These are facts well known to stratigraphers, and of nearly universal acceptance, and a few hours' research by Du Toit in the classic works by Waagen or Girty should have convinced him of his very erroneous and unsupported verdict.

On pages 77-78 we have an equally amazing statement where he is treating of the *Glossopteris* flora: "In making age determinations we have to eliminate the preponderant southern element as being of no direct value [i. e., the most important and a *new* element in the *Glossopteris* flora is valueless in correlation], though, of course, the assemblage is closely related to the floras of the equivalent Talchir-Kárhárbári series of India, the Gröta Coal Measures of New South Wales, and the Ecca Coal Measures of South Africa. Considering merely the northern forms, the five just mentioned [*Lepidophloios laricinus*, *Sigillaria brardii*, *Lepidodendron pedroanum*, *Sphenophyllum oblongifolium*, and *Lycopodiopsis derbyi*], together with *Samaropsis* (*Cardiocarpon*) *barcellosa*, are all identical with or very closely related to typically upper Carboniferous species, and in my opinion form useful confirmation for a pre-Permian age, such as has been arrived at from other considerations, though this view differs radically from the conclusions reached by D. White and certain others." In other

words, primary correlation value is laid on the hold-overs of the older cosmopolitan flora and not on the new developments seen in the *Glossopteris* one. Certainly in this no stratigrapher will agree with Du Toit.

On the other hand, the writer accepts the following correlation. "The exclusive presence of *Mesosaurus* and the outstanding lithological similarities, down to minutiae, render the *correlation of the Iraty group* [of Brazil] *with the White band of the Dwyka series* [of Africa] *absolutely assured*, although a distance of 6,300 km. separates their nearest outcrops" (p. 80). What of it? It is by no means the only instance of such wide distribution of marine animals.

In speaking of the wonderful reptilian and amphibian fauna of the Beaufort beds of southern Africa, Du Toit says that the forms appear "earliest in the southwestern corner of the Karroo . . . spreading thereafter to the northeast, through East Africa to Madagascar, India, and even Russia, accompanied by members of the *Glossopteris* flora" (p. 105). Truly so, but where did they come from, and why did they not spread across to the Falklands and into South America? "Appearing first in the southwestern corner of the Karroo," it is all the more remarkable to see on Du Toit's interesting map on page 116 how short was the distance thence to the Falklands and across to Argentina, a region that furthermore must have been the southern land for his "immense area of open water, the black, sulphureted . . . land-locked [*Mesosaurus*] sea like the Gulf of Bothnia" (p. 105), and yet why did not a single genus of the many dozens known in Africa get into South America? Why does Du Toit fail to face so striking a problem as this one that stands against his hypothesis? And furthermore, why does he nowhere in his book face the other great problem, Why was it that South America, which at no time, according to his hypothesis, was fastened to Africa, finally moved thousands of kilometers to the west? Wegener also fails to meet this problem, though Daly heroically tries to answer it.

The geological resemblances between Africa and South America, Du Toit tells us, are "nothing less than extraordinary," implicating "vast territories," and embracing "times ranging from pre-Devonian almost to the Tertiary. . . . and are of a stratigraphical, lithological, palaeontological, tectonic, volcanic, and climatic nature" (p. 109). In Chapter VII he synthesizes the previous discussion of 108 pages and brings out once more these similarities and analogies, along with some dissimilarities, grouping them in eight paragraphs, according to latitude and otherwise; they cover six pages. In detail they amount to fifty-one counts, a number which he believes must convince anyone in favor of his view that Africa and South America were at least closely adjacent, if not actually united, to one another up into early Mesozoic time.

The presentation is overwhelming, not because of the correctness of all or even of most of his interpretations, but because of his unbounded enthusiasm and his ability at special pleading. To meet these fifty-one counts with detailed counter arguments would take even more space than the length of his book; and in the end quite a number of them would remain as actually existing similarities and analogies. Such, however, have long been known and explained by paleogeographers. Granting this, does it follow from the various favorable counts that South America once lay adjacent to Africa? Or, as Du Toit states it, "from which it will be conceded that the evidence so far would distinctly appear to favor the displacement hypothesis rather than orthodox ideas?" However, his enthusiasm has not completely blinded him, since he adds: "It is nevertheless highly desirable that more impartially minded persons should criticize the data here given and judge whether those amazing resemblances have been correctly interpreted or whether some more rational explanation for them could not be formulated" (p. 115).

Finally, however, Du Toit himself becomes shaky about his interpretations of the similarities and analogies and feels obliged to differ from Wegener's close union of Africa and South America. He says: "Actual contiguity of the opposed shore-lines can most definitely be ruled out, and, secondly, even apposition of the borders of the continental shelves, as favored by Wegener, may perhaps hardly be warranted, for utilizing the line of reasoning based on *phasal variation*, the differences actually noticed between the various facies of the equivalent formations where they come closest together are of such a degree as to demand a fairly wide gap. *One of the order, perhaps, of from 400 to 800 km., would indeed seem to be needed, if all the observed phenomena are to be satisfactorily accounted for*" (p. 115). This admission of the existence of a wide gap is to the writer of the greatest significance, and with his orthodox views he sees the gap as having been never less than it is to-day.

Now, let us meet the many findings of Du Toit more directly, not in detail but in collective form, and explain them according to orthodox geologic ideas. In the first place, Africa, of all continents, is the one that has been least transgressed by the oceans since the beginning of Paleozoic time. It, therefore, stood variably high above sea-level and gathered the greatest amount of Permian and Triassic continental deposits with the very interesting land-life of these periods. During Permian time the climate started in with a glacial one that soon became warmer and hospitable to life and then changed more and more, but somewhat irregularly, to more arid and warmer conditions. The same stratigraphic, climatic, and biotic conditions are true of Peninsular India, and of the greater eastern part of South America,

though here the rock sequence is less perfect and especially the record of the land vertebrates, which are almost completely absent, though the floras are about equally rich. Accordingly, there should be striking similarities, as there are, between the floras, and above all, in the lithologic makeup, and this is especially true for Afro-America. On the other hand, the fact that this sequence ends in both continents in very similar outpourings of lavas and in tremendous volume, the writer connects with the beginning of the downbreaking of the Atlantic bridge, and when this downbreaking is completed in early Cretaceous time, very similar marine faunas appear on both sides of the Atlantic.

Back of the Permian in South Africa lies the Cape system, "some 3,300 meters in thickness," above which come the Witteberg formation (600 meters) and then another series of strata before the tillites of the Permian are met with. In all of these strata there is but one well-dated horizon, the Bokkeveld, which gives an unmistakable late Lower Devonian linkage with South America. The Table Mountain sequence, 1,600 meters thick, is always spoken of as Lower Devonian, but no one has yet demonstrated its age and it may be of Ordovician or Silurian time. Until determinable fossils are found and more attention is paid to the disconformities that must exist in South Africa, and that have so far been passed over, it is useless to attempt comparisons with similar looking formations in South America. Lithologic correlations, such as in the old days led to innumerable errors, have long been abandoned in North America. In eastern South America the older formations are also very poorly dated, and we have only Derby's conclusion that at the top they are of Silurian age. *Favosites*, *Chaetetes* (which is some monticuliporid bryozoan), and *Spirifer* have been mentioned, but these do not prove Silurian time since they may also be of the Devonian; what we should know here is the specific development. Enough has been said to show that no demonstrable correlation is possible back of the Lower Devonian.

Over and over again, because he finds in the rock sequences no unconformity (he appears to be working under the hypothesis that all breaks in sedimentation are indicated by angular or easily seeable unconformities), Du Toit speaks of perfect conformities, and hence of one unbroken sequence. Even though the fossils are known to be of different *periods* (this term is here used as in all text-books, i. e., as synonymous with system), he goes on and writes, as in discussing his Paganzo system and the tillite succession near San Juan, of perfect conformities. Until demonstrated by fossils there is no proof that a thick or even a thin formation is without depositional breaks. The "non-readily seeable breaks," the disconformities, have fooled all stratigraphers, and the number of these breaks is beyond belief until one has learned of them

through sad experience. Finally, the writer has no faith in Du Toit's "variation in facies" (p. 16) as a means of demonstrating close union between Africa and South America.

The writer has long been studying the faunal and floral assemblages of western Gondwana, and for about thirty years he has been impressed with the general correctness of the reconstruction of this continent as first presented by Neumayr and given wide acceptance by Suess. According to this interpretation, the two continents have not moved geographically in greater amounts than are demanded to compensate for the folding and faulting found in the orogenic or mountain areas; and into early Cretaceous times they were united by a wide land bridge, which, according to newer knowledge, began in earliest Jurassic time to break down into what is now the middle region of the Atlantic Ocean, the actual completed break, however, not being in evidence until about latest Lower Cretaceous time in both Brazil and western central Africa. To which reconstruction, however, the writer has, during the past few years, been postulating borderlands widely to the south and less so west of the Cape geosyncline of South Africa, and yet another regulation borderland to the east of Du Toit's Paraná basin (as illustrated on his page 116). Outside of these now mostly sunken borderlands lay what our author calls the Mesosaurus sea, which is nothing more than the Permian representation of the acceptable northern termination of Von Ihering's Nereis ocean. Granting this interpretation of western Gondwana, orthodox geology can then harmonize all the facts seen and brought together in Du Toit's book—in fact, many others of an organic nature that he is silent on—and besides, it does not have to find the reasons for the origin of a Pangea and the extraordinary late Mesozoic flight of its various parts away from Africa. Of course, according to the Neumayr paleogeography, orthodox geology has not yet come to a general acceptance of any theory explaining how these extensive land bridges go beneath the oceanic waters, and yet we are all agreed that vast continental masses have broken down into the marine basins. That continental down-fracturing is a fact is seen in Madagascar and India, which were once parts of Africa; and even more strikingly in the vast Australasian continent that has been partially broken down and reconstructed into the remainders seen to-day.

CHARLES SCHUCHERT.

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SCIENTIFIC INTELLIGENCE.

CHEMISTRY.

A Comprehensive Survey of Starch Chemistry; by ROBERT P. WALTON. Vol. I, pp. 360. New York, 1928 (The Chemical Catalog Co., \$10.00).—The title of this extraordinarily valuable book aptly describes its contents. The first section treats of various phases of the chemistry and technology of starch. Fully appreciative of the fact that the complexity and scope of the subject make it quite impossible for one person to write an authoritative treatise, Walton has enlisted the co-operation of other scientists. Consequently each topic is ably discussed by an outstanding investigator or specialist in that particular field. Such eminent names as Pictet, Irvine, Pringsheim, Alsberg, Fernbach, Alexander, Takamine and Sherman are among those who have contributed to the nineteen topics comprising the first, or so-called "symposium" section of the book. Part two is a bibliography of starch chemistry. It is admirably divided by subject into chemical, physical, analytical, technological, and amylase sections. The value of a comprehensive bibliography of this subject is too evident to require comment. In passing it should be mentioned that a second volume, giving a survey of patent literature, is contemplated by the author.

In the preface Mr. Walton states, in explanation of his motive in compiling this work, that "it is hoped that this volume of authoritative chapters and bibliography will serve to correlate the divergent types of investigation in this field, to provide the researcher with an encyclopedia of previous observations and to furnish to those indirectly interested, a readily available exposition of the subject." The reviewer can give no heartier commendation than by saying that this objective has been fully attained.

A. J. HILL.

GEOLOGY.

The Geology of Venezuela and Trinidad; by RALPH A. LIDDLE. Pp. xxxix+552, 83 pls., 21 figs., geol. map, 1928. Fort Worth, Texas (J. P. MacGowan), \$7.00.—For five years the author of this work has been continuously exploring all parts of Venezuela, to unravel the geologic sequence in that large country for the Standard Oil Company of New Jersey, and he now publishes the only general treatise we have of this part of South America. It describes in considerable detail and from place to place the entire geology of Venezuela and Trinidad, from the most ancient granites of the Guayana shield to the most recent rocks along the Caribbean shore. The greater part of the book, however, treats

of the Cretaceous and Tertiary formations, which are in fine development and often have an abundance of fossils, the Oligocene and Miocene formations being especially detailed. It is our most valuable work on northern South America, not only for teachers of geology but even more for the economic geologist in search of petroleum.

Liddle has accepted at face value the fossils described by Drevermann and supposed to have been collected near Valencia. It is certain that these fossils are Silurian in age but in reality from Wisconsin, but how the German engineer got them from Valencia is still unknown. However, Liddle himself has collected Middle Devonian fossils in the Venezuelan Andes, and similar ones are known in northeastern Colombia, so it is possible that most of the metamorphic Caribbean series is of Paleozoic age. These are the only fossils so far known in Venezuela older than the Lower Cretaceous. Accordingly much is yet to be learned of the historical geology of the country back of the Cretaceous period:

C. S.

Foraminifera, their Classification and Economic Use; by JOSEPH A. CUSHMAN. Cushman Lab. Foram. Research, Special Pub. No. 1, 1928 (\$5.00). Pp. 401; 59 pls., and text figs.—A general treatise on living and fossil Foraminifera has long been needed, and now we have a good one by the foremost specialist in this class of organisms. It is a very helpful book, describing in the main 45 families that have 412 genera (properly placing in addition 195 synonyms). Of these more than 400 are illustrated, making it easy for the worker to identify his material at least generically. Other parts of the work deal with the animal itself (6 pp.), test (10 pp.), collecting, preparing, and methods of study (12 pp.), economic use (5 pp.), and geographic and geologic distribution (11 pp.). The complete bibliography on Foraminifera has now between 4,000 and 5,000 titles, and out of these the more useful ones have been selected (pp. 362-392). The illustrations are in the main arranged on full-page plates.

We congratulate the author upon his labor of love, and predict that all the paleontologists in and out of economic laboratories will sing his praises.

C. S.

An Examination of the Tertiary and Quaternary Changes of Sea-level in South Africa; with special stress on the evidence in favour of a recent world-wide sinking of ocean-level; by A. V. KRIGE. Annals Univ. of Stellenbosch, Vol. 5, Sect. A, No. 1. Cape Town, May 1927. Pp. 81, 5 pls. and large map.—This paper gives the results of a remarkable study, begun at the suggestion of Professor R. A. Daly, of the whole coast of the Union of South Africa, excluding Zululand, representing fully 1800 miles (2900 km.). It deals with the changes of level of land and sea, with the fluctuations of the shoreline, the title being misleading.

Since the early Tertiary, South Africa has, according to this study, undergone, besides smaller fluctuations of level: (1) Tertiary-Quaternary emergence, (2) Quaternary immergence, and (3) late-Quaternary emergence. However, the history will, no doubt, prove to be more complicated.

1. *Emergence*.—The highest marine terracè observed lies at an altitude of 4000 feet (1220 m.). The emergence of the land was interrupted a few times as indicated by extensive terraces at 2500 and 1000 to 800 feet (762 and 305 to 244 m.), and by smaller terraces at roughly 550 to 450 and 250 to 150 feet (168 to 137 and 76 to 46 m.). All the five terraces are of Tertiary age, the last three being in part covered by a veneer of marine Mio-Pliocene sediments.

The regression of the shoreline continued to below the present position. It proceeded at least to the isobath of 50 to 55 fathoms (300 to 330 feet, 90 to 100 m.), so that part of the Agulhas Bank was laid bare, and it proceeded possibly to the isobath of 400 fathoms (2400 feet, 730 m.). This superelevation occurred between the late Tertiary and the late Quaternary, for the deep river mouths, corresponding to the low shoreline, are filled with Pleistocene and recent deposits.

The regression of the shoreline from the 4000-foot level to about the present position may have been essentially due to upheaval of the land. During the Pleistocene glaciation (which in order is not stated), according to A. L. du Toit, the sea level may have been lowered some 90 to 100 m. by withdrawal of water, and the shoreline may have retreated to the isobath of 90 to 100 m. If this view is correct, the land upheaval would have stopped when the present stand was reached. Krige is inclined to think that the uplift proceeded much farther.

2. *Immergence*.—The emergence from +4000 feet to below the modern shore was followed by immergence. The shoreline marking the limit of this transgression now stands at an average altitude of 50 to 60 feet (15.2 to 18.3 m.) but fluctuates between those of 20 and 100 feet (6 and 30 m.). It is marked by wave-cut terraces—at places three miles broad in gneiss—, sea caves, and river terraces. It was formed after the emergence of the Agulhas Bank, but its age is not well known. The transgression was in Krige's mind most probably due to sinking of the land.

It deserves pointing out that there is a terrace at about 60 feet altitude on the American eastcoast south of Hatteras and on the Western Mediterranean, a terrace that seems to date from the last interglacial.

3. *Last emergence*.—The regression from the 50 to 60-foot shoreline to the modern stand underwent oscillations marked by shore features at 20 and 14 to 12 feet (6, 4.3 to 3.7 m.) altitude. The 20-foot shore, which has been especially studied, is recorded

at suitable places all along the coast. Judging from the size of the sea caves, its development took at least as long time as has that of the modern shoreline and slightly longer than did that of the 12 to 14-foot shore. The water temperature was higher during its formation than at present, several of the molluscs found in its deposits having withdrawn to warmer waters.

The 20-foot shoreline is after Daly explained by higher stand of sea level due to shrinking of the Antarctic and Greenlandic ice sheets to below their present extent during the postglacial temperature maximum which prevailed from about 7000 to about 3000 years ago.

ERNST ANTEVS.

International Geological Congress, Meeting at Pretoria in 1929.—The fifteenth meeting of the International Geological Congress will be held at Pretoria, South Africa, in July-August, 1929. Dr. A. W. Rogers, Director of the Geological Survey of the Union of South Africa, is the President; Dr. A. L. Hall is the General Secretary. The sessions will extend from July 29 to August 7. The membership fee is one pound sterling, and applications (on the form furnished) must be received not later than July 1. The titles of papers to be submitted at the Congress must be received by the General Secretary not later than June 1st, 1929, and must be accompanied by a typewritten or printed abstract, not more than 200 words in length (in English, French or German).

Some special subjects to be discussed are: Magmatic Differentiation. Pre-Pleistocene Glacial Periods. The Karroo System; its stratigraphy, paleontology and world distribution. The Genesis of Petroleum. The Geological Work of Micro-organisms. The Congress expects to have ready for presentation valuable and important information on the Gold Resources of the World.

Twenty excursions to many interesting points (with special fee and in part limited) have been planned: (1) Before the sessions; (2) during the sessions; (3) also, longer excursions after the sessions. Applications to join excursions must be received not later than April 1st, 1929.

All communications must be addressed: General Secretary, XV International Geological Congress, P. O. Box 391, Pretoria, South Africa.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Folklore of the Teeth; by LEO KANNER. Pp. xiii, 316. New York, 1928 (The Macmillan Co., \$4.00).—What the author considers an "outline" of the folklore of the teeth seems to the reader a very comprehensive study, including all peoples and all countries of all time. This volume treats of the customs, largely the result of superstitions and traditions, the pathologic and therapeutic beliefs and measures concerning the teeth, their use outside of the

oral cavity and the various forms of their mutilation. That such an account is pleasant reading can not be claimed. Many of the customs are revolting. Further, to a singular degree, the mere reading of maltreatment of the teeth awakens a painful sensation in one's own dental parts.

A. F. M.

Infancy and Human Growth; by ARNOLD GESELL. Pp. xviii, 418. New York, 1928 (The Macmillan Co.).—The title of this interesting book will doubtless be misleading to most persons, particularly those who are not familiar with the researches of its author, the director of the Yale Psycho-clinic. Growth is usually considered in relation to gains in size, to somatic development. Form, weight and structure thus form the central themes for discussion. Prof. Gesell has, however, considered growth as an aspect of psycho-biology; hence he deals more particularly with "mental growth"—"the whole series of behavior changes which characterize the life history of the individual." The book is a systematically presented record of repeated developmental examinations of individual infants and represents a sort of pioneer effort to establish "norms" for the period of infancy. Much of the procedure developed by the author and his associates is as ingenious as it is unique. It represents, further, an effort not only to observe but perhaps also to alter the early nature of the infant. Thus, the author suggests, science may enter the outskirts of a new domain of conscious control.

L. B. M.

PUBLICATIONS RECENTLY RECEIVED.

Chemical Encyclopaedia, by C. T. Kingzett. Fourth Edition. New York, 1928 (D. Van Nostrand Company, Inc., \$10.00).

Geology of Petroleum and Natural Gas, by Ernest R. Lilley. New York, 1928 (D. Van Nostrand Company, Inc., \$6.00).

Infancy and Human Growth, by Arnold Gesell. New York, 1928 (The Macmillan Co.).

Vestiges of Pre-metric Weights and Measures, Persisting in Metric-System Europe 1926-1927; by Arthur E. Kennelly. New York, 1928 (The Macmillan Co., \$2.50).

How and Whys of Cooking; by Evelyn G. Halliday and Isabel T. Noble. Chicago, 1928 (University of Chicago Press, \$2.00).

Year Book of the Public Museum of the City of Milwaukee; by S. A. Barrett, Director. Milwaukee, 1928.

Fixation of Atmospheric Nitrogen; by Frank A. Ernst. New York, 1928 (D. Van Nostrand Co., Inc., \$2.50).

Beyond the Electron by J. J. Thomson. Cambridge, 1928 (The Macmillan Company).

The New Quantum Mechanics, by George Birtwistle. Cambridge, 1928 (At the University Press).

Photochemical Processes; by George B. Kistiakowsky. New York, 1928 (The Chemical Catalog Company, Inc., \$5.50).

Biological Chemistry and Physics of Sea Water; by H. W. Harvey. New York, 1928 (The Macmillan Co.).

The Fundamentals of Human Motivation; by Leonard T. Troland. New York, 1928 (D. Van Nostrand Co., Inc., \$5.00).

The Electrical Conductivity of the Atmosphere and Its Causes; by Victor F. Hess. New York, 1928 (D. Van Nostrand Co., \$4.00).

Water Resources of Virginia, by J. J. Dirzulaitis and G. C. Stevens. University, Va., 1927 (The Virginia Geological Survey).

Field Book of North American Mammals; by H. E. Anthony. New York-London, 1928 (G. P. Putnam's Sons).

Orokaiva Magic; by F. E. Williams. New York, 1928 (Oxford University Press, Amer. Branch, \$4.25).

Mechanics for Engineers; by Julian C. Smallwood and Frank W. Kouwenhoven. New York, 1928 (D. Van Nostrand Co., \$2.50).

Papers from the Geological Department Glasgow University. Volume XII. Octavo Papers of 1927. Glasgow, 1928 (Jackson, Wylie & Co.).

OBITUARY.

DR. SAMUEL FESSENDEN CLARKE, professor of natural history at Williams College from 1881 to 1916, died at his home in Williamstown on August 1, in his seventy-eighth year. He was graduated at the Sheffield Scientific School of Yale University in 1878. He was assistant to the United States Fish Commission in 1874-75, and fellow in biology at Johns Hopkins University in 1879-81. His original work included several publications on the hydroids and on the American alligator.

DR. PLINY EARLE GODDARD, curator of Ethnology in the American Museum of Natural History since 1914, and lecturer of anthropology in Columbia University since 1915, died on July 13 in his fifty-ninth year. The effective arrangement of the exhibition halls of ethnology in the American Museum was accomplished by him.

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Foot notes should be numbered consecutively from 1 up.

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Am. J. Sci., **44**, 249, 1917. The year should be given in every case; this renders a series number unessential.

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AMERICAN JOURNAL OF SCIENCE

OCTOBER 1928

MAJOR MARINE TRANSGRESSIONS AND REGRESSIONS AND STRUCTURAL FEATURES OF THE GULF COASTAL PLAIN.*

LLOYD W. STEPHENSON.

TRANSGRESSIONS AND REGRESSIONS OF THE SEA.

The region which we now call the Gulf Coastal Plain was, in early Cretaceous time, a land area characterized by low rolling topography, probably fitting quite well our commonly accepted concept of a peneplained surface. The area was not, however, a coastal plain but a continental tract underlain by more or less folded Paleozoic and pre-Paleozoic rocks which, during Triassic, Jurassic, and early Cretaceous time, had been beveled by erosion to an approximate base level. Just how far this land extended toward the south we do not know, but the assumption seems justified that it included all of the area that now lies above the level of the Gulf of Mexico and probably extended at least to the submerged edge of the Continental Shelf. The Mississippi embayment had not yet begun to take form.

Some time in early or middle Lower Cretaceous time the western Gulf region began to subside and the waters of the Atlantic Ocean crept inland over the base-leveled surface; but the western Gulf region was only a small part of the area affected by this downsincking movement, for, before the end of Lower Cretaceous time, western Oklahoma, western Texas, nearly all of Old Mexico, parts of New Mexico, Arizona, Colorado, and Kansas, and parts of Central America and South America had become involved in it. By middle Lower Cretaceous time most of Texas, most of Louisiana, the south-

*This paper was presented as part of a symposium on the Mesozoic and Cenozoic stratigraphy of the Gulf States, at the Nashville meeting of Section E of the American Association for the Advancement of Science, December, 1927. Published by permission of the Director of the U. S. Geological Survey.

western part of Arkansas, and perhaps southwestern Mississippi, were covered by the sea.¹ So far as is known no part of the area now embraced by the Atlantic Coastal Plain, including Florida, was submerged in Lower Cretaceous time. (See Fig. 1.) In this sea the Comanche series, predominantly limestone, was deposited to a maximum thickness of more than 3,000 feet. The oldest exposed sediments of the

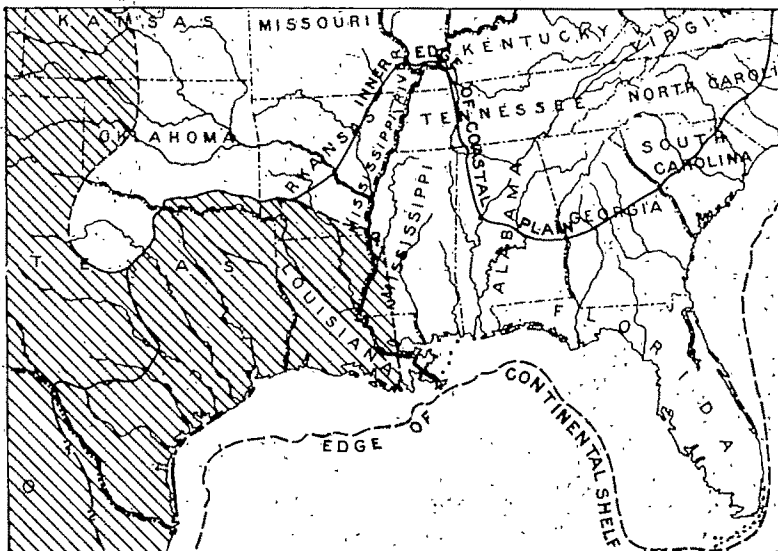


Fig. 1. Map showing area underlain by marine deposits of the Comanche series, including areas along the inner margin where these deposits have been removed by erosion.

series, the Trinity group, are, in terms of the European standard section, of Aptian age. Still older sediments of the series may lie deeply buried and overlapped by the younger sediments; and some of these older sediments may be exposed in the mountains of eastern Mexico. At the close of Lower

¹The areas in which the deposits of the different Cretaceous and Tertiary epochs were laid down are shown on the accompanying sketch maps, Figs. 1 to 11. These maps were prepared in collaboration with Dr. T. W. Stanton with respect to the Lower Cretaceous of Texas; Mr. W. C. Spooner, with respect to the Cretaceous and Tertiary of Louisiana and southern Arkansas; Dr. Julia Gardner with respect to the Tertiary west of Mississippi River; Dr. Wythe Cooke with respect to the Tertiary east of Mississippi River, and Dr. W. C. Mansfield with respect to the Miocene and Pliocene of Florida.

Cretaceous time the submerged area was uplifted, the waters retreated gulfward, and the Comanche series of sediments, the first contribution of the Atlantic Ocean to the construction of the Gulf Coastal Plain, lay exposed to the agents of erosion.

The erosion interval which followed the deposition of the Comanche series lasted long enough to produce an approximate peneplain, but in early Upper Cretaceous time the Gulf Coastal Plain again began to subside and the sea spread inland, the first inundation covering eastern and northeastern Texas, southeastern Oklahoma, and southwestern Arkansas. The earliest stage of this submergence is recorded in the shallow-water Woodbine formation of Cenomanian age. The inundation spread relatively quickly in the western Gulf Coastal Plain, and simultaneously in the Rocky Mountain region of the west a geosynclinal subsidence took place, which permitted the ocean waters to produce a greatly elongated epicontinental sea extending from the Gulf region to the Arctic Ocean in far northwestern Canada. The inundation also spread to the east and northeast along the Atlantic border region and before middle Upper Cretaceous time had covered most of the present Atlantic Coastal Plain as far as Martha's Vineyard, Massachusetts. Well records, as interpreted by W. C. Spooner,² show that during most of Upper Cretaceous time there was an island in the area of the Monroe and Richland gas fields in northeastern Louisiana, and in the Richland area this island probably remained above water during all of the Upper Cretaceous epoch. (See Fig. 2.)

The Upper Cretaceous submergence is recorded in the Gulf series of sediments. The lowest of these sediments are irregularly bedded sands and clays, sometimes classed as of continental origin, but they should perhaps more properly be regarded as of shallow marine, estuarine, lagoonal, and only subordinately of continental origin. The irregularly-bedded sediments are overlain by shallow- to moderately deep-water marine sands, clays, marls, and chalks, which make up the bulk of the Gulf series. Unconformities within the series record minor retreats and advances of the sea in parts of the area. The downwarping of the Mississippi embayment appears to have begun during the early part of the Upper Cretaceous, and toward the close of that epoch the sea had spread northward to the southern end of Illinois.

² Oral communication.

A general uplift of the North American Continent at the close of Upper Cretaceous time caused the ocean waters to retreat, not only from the Atlantic and Gulf Coastal Plain, but also from the great inland sea of the Western Interior. Although definite proof is wanting as to the extent of this retreat, the great difference between the fossil faunas of the uppermost Cretaceous and the lowermost Eocene justifies the assumption that the whole of the continental shelf of eastern

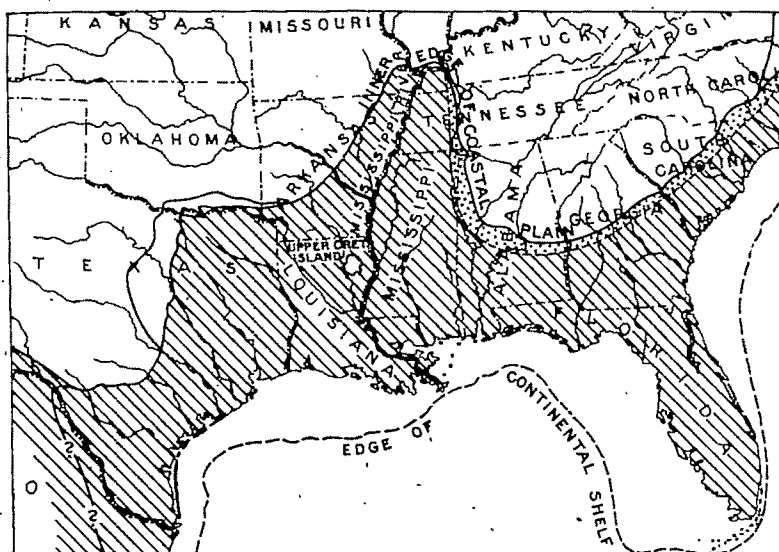


Fig. 2. Map showing area underlain by deposits of the Upper Cretaceous (Gulf) series, including some narrow strips along the inner margin where these deposits have been removed by erosion. Ruled area marine; dotted area brackish water and nonmarine.

North America became land. Again, the region was approximately base-leveled, and the materials removed from the area during this erosion interval were carried far out to sea perhaps to a zone just outside the edge of the continental shelf, and now lie deeply buried beyond the reach of man's most ingenious drilling machinery. That appears to be the answer, so far as the Atlantic border is concerned, to the oft-repeated question, "May we not some day find marine deposits intermediate between the Cretaceous and the Eocene?" I do not anticipate that such intermediate deposits will be found in this region.

After a period of considerable length, even as measured in geologic time, the Gulf region again subsided and the Midway Eocene sea spread inland. But this inundation was much more restricted in its extent than was the preceding Upper Cretaceous sea; it did not cover all of western Texas, and so far as known, none except the extreme southern part of the Atlantic Coastal Plain; it did, however, sweep northward to the head of the Mississippi embayment in southern Illinois as a result of renewed downwarp there, and in Georgia reached

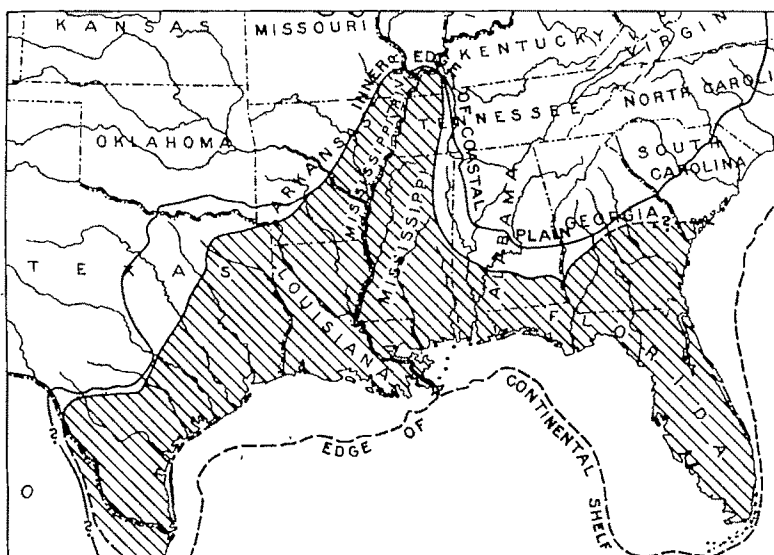


Fig. 3. Map showing area underlain by marine deposits of the Midway formation, including some narrow strips along the inner margin where these deposits have been removed by erosion.

almost to the inner edge of the Coastal Plain. (See Fig. 3.) The Midway sediments are of marine origin. In parts of the Gulf region there is an unconformity between the deposits of the Midway formation and those of the overlying Wilcox group, and where present this break marks a retreat of the sea, and the retreat may have been general in the region.

The Midway formation is overlain by the Wilcox group, which is composed largely of nonmarine and shallow marine sands and clays though beds of deeper marine origin compose it in part, especially in the eastern Gulf region. In the Gulf

region the Wilcox sea did not extend inland as far as the Midway sea. Although the group is composed in considerable part of lagoonal, estuarine, and fresh-water flood plain sediments, their deposition was controlled by sea level as is evidenced by the distribution of their belt of outcrop which trends parallel to the coast from the Rio Grande to South Carolina, a distance of over 1,400 miles; the Wilcox is also represented in the lower part of the marine Eocene Pamunkey group of the North Atlantic Coastal Plain. The Wilcox

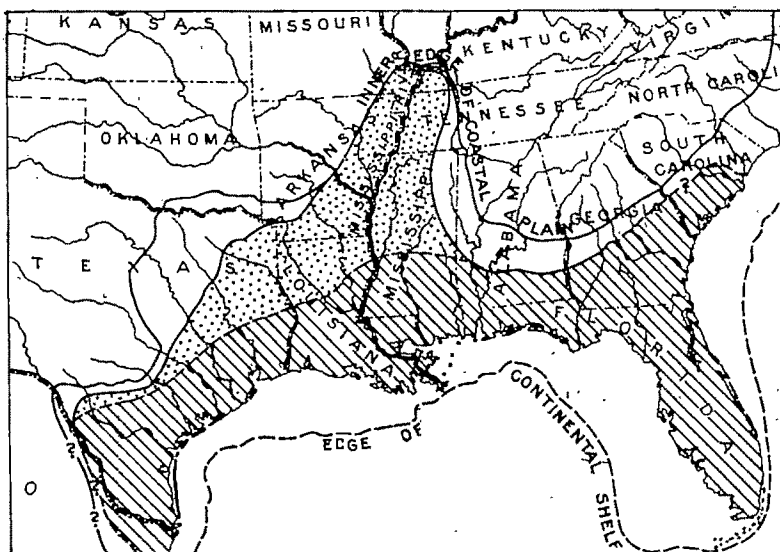


Fig. 4. Map showing area underlain by deposits of the Wilcox group, including some narrow strips along the inner margin where these deposits have been removed by erosion.

Ruled area, marine; dotted area, brackish water and nonmarine.

group of the Mississippi embayment and western Gulf region probably merges down the dip into sediments of true marine origin. Wilcox deposits extend to the head of the Mississippi embayment, but in the embayment proper the beds are composed largely of sands and clays laid down on a low plain somewhat above sea level, which records a continued slight downwarp of that area. In Georgia the Wilcox group is overlapped and partly concealed by younger formations. (See Fig. 4.)

The deposition of the Wilcox sediments was brought to a

close by uplift or tilting of the land followed by a period of erosion. Subsequent downsinking permitted the waters of the sea to spread inland over the eroded surface of the Wilcox formations, and in this sea were deposited the dominantly marine sands, clays, and marls of the Claiborne group. But the Claiborne sediments are more restricted in their distribution than those of either the Wilcox or the Midway, and the sea fell more than a hundred miles short of reaching the head of the Mississippi embayment. (See Fig. 5.) The Clai-

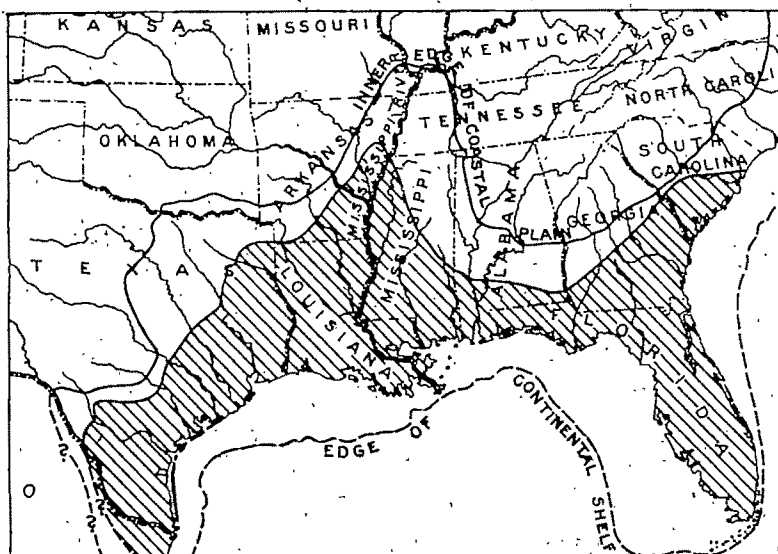


Fig. 5. Map showing area underlain by marine deposits of the Claiborne group, including some areas where these deposits have been removed by erosion.

borne deposits were probably laid down over the area now occupied by the Sabine uplift, but were later removed by the erosion which resulted from the updoming of that district. Claiborne sediments are not certainly known in the north Atlantic Coastal Plain, though the upper part of the Eocene Pamunkey group may be of that age.

At the close of the Claiborne epoch there was a shallowing of the sea, as indicated by lignitic sands and clays at the top of the group, and there was probably sufficient uplift in places to produce emergence and erosion, before the Jackson sea

inundated the area. In the Gulf region the waters of this sea were more restricted in their transgression than were those of the Claiborne, except in the Mississippi embayment, whose renewed downwarping permitted the Jackson sea to spread northward about to the latitude of Memphis, and nonmarine Jackson deposits were laid down nearly to the head of the embayment, the surface of which stood but little above sea level. In Georgia and southwestern South Carolina a broad downwarp allowed the sea to sweep inland across all the older

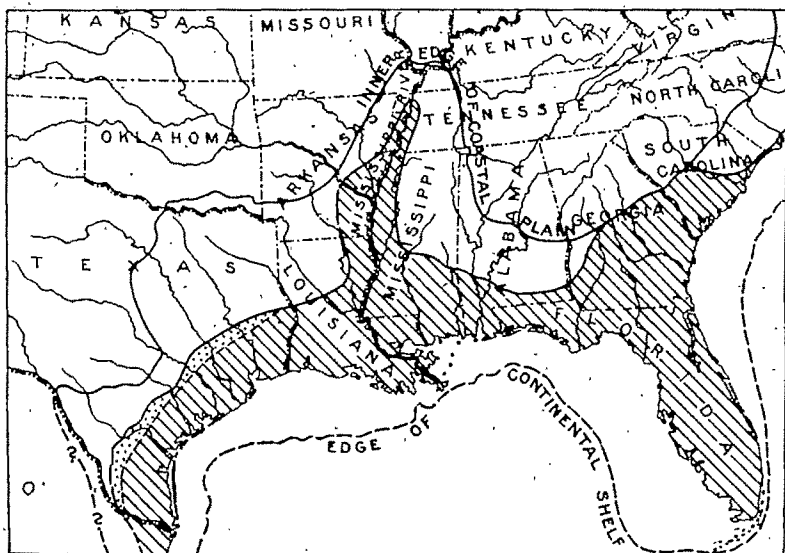


Fig. 6. Map showing area underlain by deposits of Jackson age, including some narrow strips along the inner margin where these deposits have been removed by erosion.

Ruled area, marine; dotted area, brackish water and nonmarine.

deposits to the inner edge of the Coastal Plain. Farther north a broad upwarp which had its axis in southeastern North Carolina forced the strand line of the Jackson sea out almost to the present coast where Jackson sediments now rest upon the Upper Cretaceous. In eastern North Carolina the beds of Jackson age pass under the Miocene and are not known anywhere in the North Atlantic Coastal Plain. (See Fig. 6.)

In the central and eastern parts of the Gulf Coastal Plain the Jackson sediments are followed without conspicuous evidence of unconformity by the Oligocene marine sands, clays,

limestones, and marls of the Vicksburg group, but the Vicksburg sea did not extend quite so far north as the Jackson sea. In southwestern Louisiana and southern Texas the Vicksburg is completely overlapped by beds interpreted to be of lower Miocene age, and in that area it is known only in wells. It may subsequently be shown, however, that some of the non-marine beds in Texas which are here included in the lower Miocene are of Oligocene age. In eastern Alabama and western Georgia the Oligocene sea transgressed somewhat to

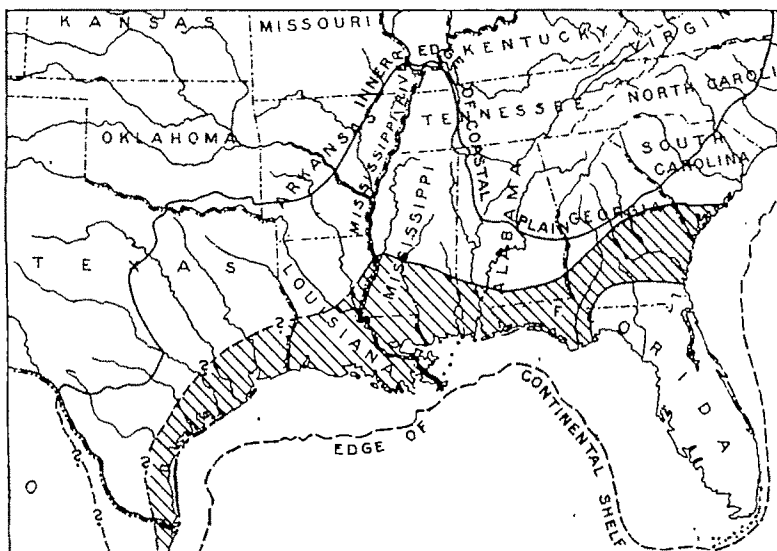


Fig. 7. Map showing area underlain by marine deposits of Oligocene age, including some narrow strips along the inner margin where these deposits have been removed by erosion. Florida was an island during that epoch.

the north over the Eocene deposits but farther to the northeast did not spread quite so far inland as the Jackson sea. In eastern Georgia the Oligocene strata are in turn transgressed and concealed by Miocene deposits except in one relatively small area in Savannah River Valley where erosion has uncovered them, and the Oligocene is not known in the Atlantic Coastal Plain north of the last named locality. (See Fig. 7.)

The deposition of the Oligocene Vicksburg group was followed by uplift or tilting, the retreat of the strand line sea-

ward, and erosion in the formerly submerged area. In the central part of the Gulf Coastal Plain this eroded surface was later partly covered by lower Miocene deposits which, however, do not extend quite so far inland as the Vicksburg group. In southern Louisiana and in southeastern Texas, the Catahoula sandstone (interpreted to be lower Miocene) and its equivalents overlap the marine Oligocene sediments of Vicksburg age, which, as previously stated, are known only in wells, except one small area of outcrop near Roseland in the northern

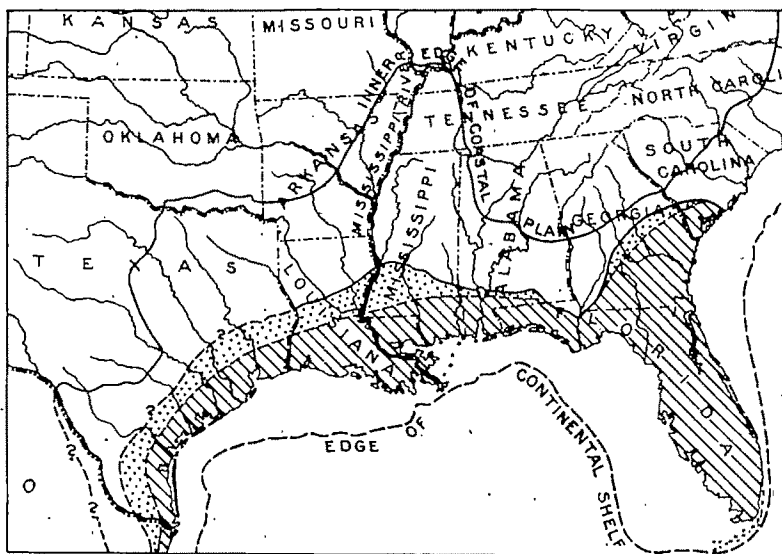


Fig. 8. Map showing area underlain by deposits of lower Miocene age, including some narrow strips along the inner margin where these deposits have been removed by erosion.

Ruled area, marine; dotted areas, nonmarine.

part of Catahoula Parish, Louisiana. In eastern Georgia the Vicksburg is completely overlapped by the lower Miocene. (See Fig. 8.) From Mississippi westward the lower Miocene sediments are in large part of nonmarine origin, but their distribution parallel to the coast suggests that their deposition was controlled by sea level. They were doubtless laid down in part in the shallow littoral waters of the sea, for some of them carry marine fossils, in part in bays, lagoons, and estuaries, and in part as delta deposits on low plains bordering the sea. In the Florida peninsula and from there north-

ward along the coast the lower Miocene deposits are mainly of marine origin. Lower Miocene deposits have not been recognized in the Atlantic Coastal Plain north of Neuse River, North Carolina.

Upper Miocene deposits have been recognized in outcrops in Texas, Louisiana, southern Mississippi, southern Alabama, and northwestern Florida. In the central and eastern parts of the Gulf region the deposits are much more restricted in extent than those of the lower Miocene. In Florida the deposits are

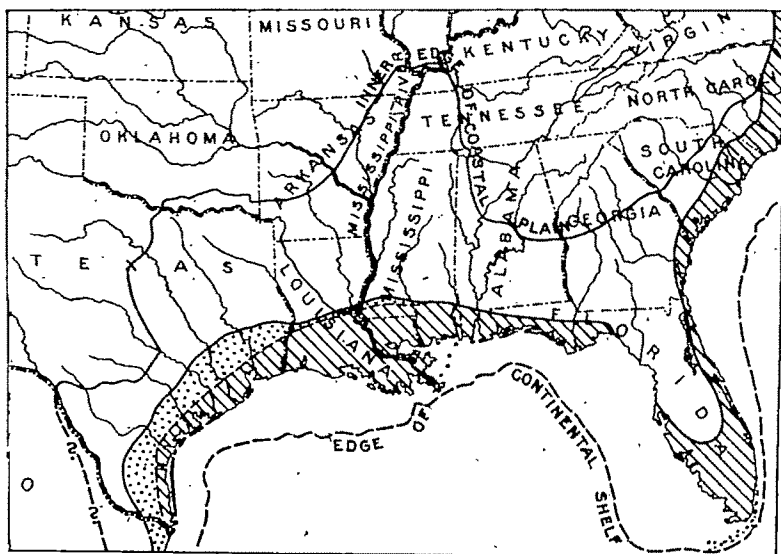


Fig. 9. Map showing areas underlain by deposits of upper Miocene age, including some tracts where these deposits have been removed by erosion. Ruled areas, marine; dotted area, brackish water and nonmarine.

marine; and farther west they are in part shallow marine, but are largely nonmarine. In the north Atlantic Coastal Plain the upper Miocene sea, in contrast to that of the Gulf region, swept inland across all older deposits, and in North Carolina and Virginia reached the inner edge of the Coastal Plain. (See Fig. 9.)

The Pliocene sediments of the Gulf region west of Florida are largely of nonmarine origin and were laid down unconformably on the older deposits chiefly as coalescing alluvial accumulations on a low plain bordering the coast. In Missis-

issippi and western Alabama these deposits (the Citronelle formation) spread northward across Miocene, Oligocene, and uppermost Eocene formations, but they are there relatively thin and the underlying, overlapped formations are exposed by erosion in all the valleys except the small headwater tributaries. The Reynosa formation of Texas, of probable Pliocene age, which forms a continuous outcropping band across the State, has also many transgressive, though scattered erosion remnants far inland over the older formations. (See

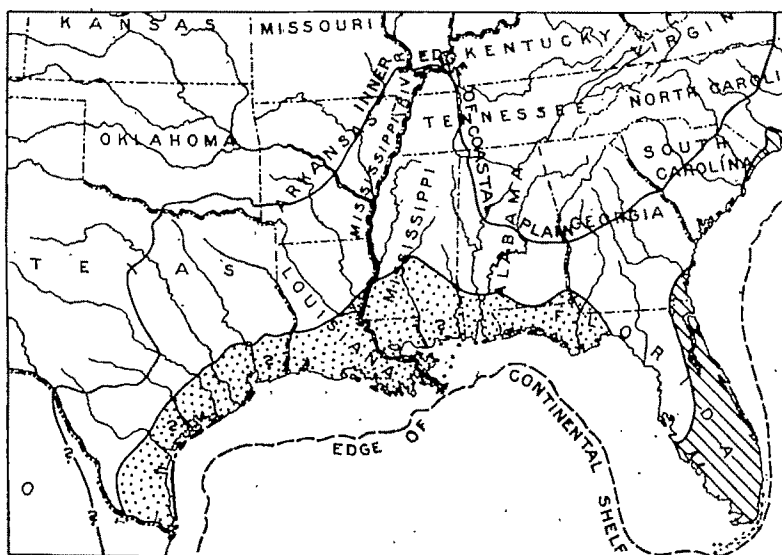


Fig. 10. Map showing areas underlain by deposits of Pliocene age, including some narrow strips along the inner margin and along streams, where these deposits have been removed by erosion.

Ruled areas, marine; dotted area, brackish water and nonmarine.

Fig. 10.) The Pliocene is represented by marine deposits in southern and eastern Florida, and discontinuously along the Atlantic Coast as far north as the southern part of North Carolina. At many places on the higher interstream uplands of the Coastal Plain are erosion remnants of greater or less extent, of relatively thin surficial deposits of gravel, sand, and loam of probable Pliocene age. These were formed by ancient rivers which flowed in meandering channels across the Coastal Plain. They have never been mapped in detail.

The last addition to the upbuilding of the Coastal Plain

is the band of Quaternary sediments (Pleistocene and Recent) immediately bordering the Coast. (See Fig. II.) These deposits are probably in part of marine and in part of non-marine origin. Terrace deposits of Quaternary age, for the most part relatively thin, also blanket the older formations at many places inland from the Coast to, or even beyond, the inner margin of the Coastal Plain. In the Gulf Coastal Plain these are of both marine and fluvial origin, and the Pleistocene and Recent flood plain deposits of Mississippi

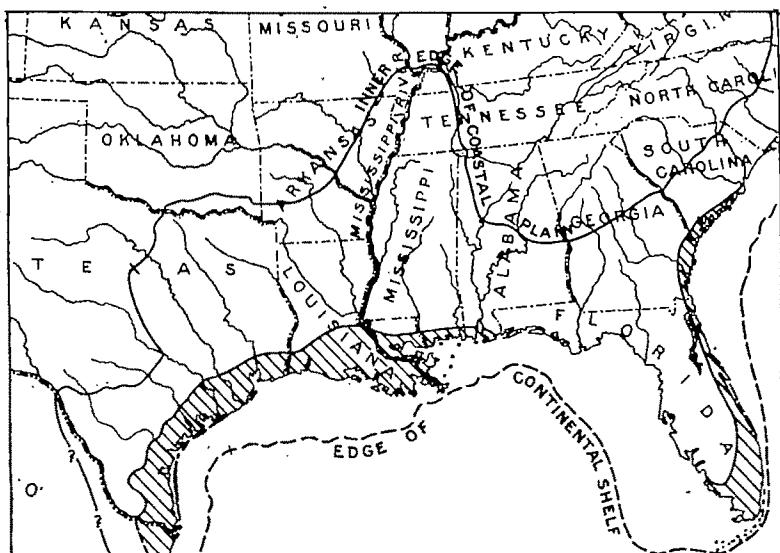


Fig. II. Map showing deposits of Quaternary age near the Coast, including those of both marine and nonmarine origin. Surficial deposits of the same age (both marine and nonmarine) in many other parts of the Coastal Plain are not represented.

River form the thickest and most extensive covering of this class.

STRUCTURE.

The strata composing the Gulf Coastal Plain lie in a monoclinal attitude with a gentle dip toward the coast, and this characteristic serves to distinguish the Coastal Plain from the adjacent physiographic provinces which are characterized by uplift and structural deformation of one kind and another. The sediments as a whole form a wedge-shaped mass along

the Gulf border region, with the blade of the wedge represented by the thin feather edge of sediments along the inner margin of the plain. The maximum thickness of the other end of the wedge along the coast is not known, but some geologists have estimated that, if the known thicknesses of the Cretaceous and Tertiary formations are maintained seaward, the total thickness of the sediments of the Coastal Plain at the coast should be something like 25,000 feet. Positive data on the maximum thickness of the sediments are meager and totally inadequate, but a few deep wells in different parts

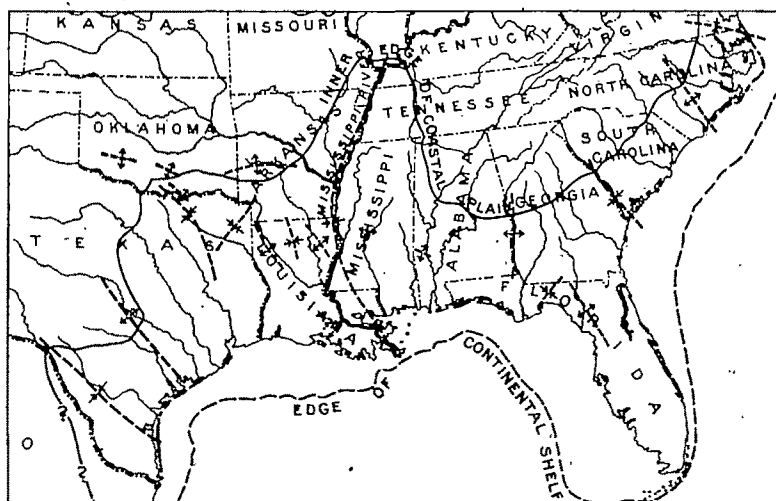


Fig. 12. Map showing principal axes of anticlinal and synclinal warping in the south Atlantic and Gulf Coastal Plain.

of the area indicate that great thicknesses of sediments make up both the lower and older and the upper and younger parts of the Coastal Plain section, and it seems certain that the maximum thickness of the section exceeds 15,000 feet.

A thickness of 25,000 feet at the large end of a wedge of these sediments may seem to suggest a large and important feature, but when looked at in its true proportions the wedge diminishes to a relatively minor feature. If a graphic section of the sediments of the Coastal Plain be drawn without vertical exaggeration from the head of the Mississippi embayment in southern Illinois to the Gulf at the mouth of Mississippi River, such that the length of the 575-mile section be 10 feet,

then on the assumption of a thickness of sediments of 25,000 feet the large end of the section would be only 1 inch high. A similar section drawn to the same scale across the Texas Coastal Plain at its narrowest part of 135 miles in the valley of Guadalupe River would be about 2 feet 4 inches long, and 1 inch high at the coastal end; this would represent a proportionately somewhat thicker covering of sediments, but still the covering would be relatively thin. On a scale of 1:1,000,000, a covering of sediments 25,000 feet thick at the coast would be only about 0.3 of an inch thick.

We may therefore picture the Gulf Coastal Plain as made up of a basement of more or less folded, eroded, and base-leveled pre-Paleozoic and Paleozoic rocks, overlain by a mere veneer of sediments of Cretaceous, Tertiary, and Quaternary age. Viewed in this way it is apparent how readily any pronounced movement in the basement rocks might warp or disrupt the strata composing the thin, shell-like covering of sediments.

With this general conception of the make-up of the Coastal Plain, attention may be called to some of the structural features that modify it. (See Fig. 12.)

The Mississippi embayment is a broad, shallow down-warped sediment-filled trough plunging gently toward the Gulf.

Peninsular Florida is a broad slightly upwarped area with the axis trending north-northwest.

Chattahoochee River on the Georgia-Alabama line flows southward on a broad upwarp whose axis trends nearly north and south. The Chattahoochee and Florida upwarps are separated from each other by a shallow syncline which plunges gently toward the southwest.

In the area between the Chattahoochee upwarp and the Mississippi downwarp are several structural features that have attracted attention. Most conspicuous of these is the Hatchitigbee anticline which trends northwest-southeast in west-central Alabama; it is 50 miles long by 20 miles wide, and exhibits a maximum uplift of 600 or 700 feet above the normal position of the beds involved in the folding. To the southeast of this anticline is the Jackson fault, a curved north-south fracture 17 miles or more in length, which exhibits a maximum uplift on the east side of the fault of 450 feet. A displacement of 300 feet has been reported in one fault in Wilcox County, Alabama, and minor faults are abundant

in Upper Cretaceous chalk in the same county. An upwarp of the anticlinal nose type with axis trending south 32 degrees west, has been described at Jackson, Mississippi, and very gentle southward dipping monoclines have been described near Vicksburg, Warren County, and near Eldorado, Yazoo County, Miss. The New Madrid earthquake of 1811 in the northern part of the Mississippi embayment probably resulted from faulting in the basement rocks underlying the sediments of that part of the Coastal Plain.

Several major structural features which may be discriminated in the Gulf Coastal Plain and adjacent inland areas west of the Mississippi embayment are: (1) The combined Monroe and Sabine uplifts of northern Louisiana (separated by a shallow syncline); (2) the east-Texas embayment, a very broad downwarp west of the Sabine uplift and south of the Arbuckle and Ouachita uplifts, having its main axis trending in a northwest-southeast direction; (3) the Llano uplift, a dome-like uplifted area just northwest of the Coastal Plain proper, with axis trending northwest-southeast, whose updoming produced a broad gentle arching in the formations of the Coastal Plain to the southeast, and also caused the faults of the Balcones fault zone, for the zone lies concentrically around the uplift; and (4) the Rio Grande embayment, another broadly downwarped area in southern Texas.

The Preston anticline is a pronounced fold lying a little east of the northwestern end of the axis of the East Texas embayment, and the Leonard-Celeste anticlinal nose is a lesser fold southeast of the Preston anticline and probably genetically related to it.

The Balcones fault zone bounds the inner edge of the Coastal Plain from Uvalde County eastward and northeastward to Austin, Travis County, and thence extends northward into the Coastal Plain at least as far as Bell County. The faults are normal with downthrow to the south and southeast and the combined vertical displacement probably amounts to a maximum of 1,000 feet. The latest pronounced movement probably occurred in early Pliocene time and many of the scarp faces are still clearly expressed in the topography.

The Mexia-Powell fault zone is a long, narrow zone of faulting which is traceable, with certain interruptions, from Uvalde County, Texas, in the southwest to Titus County, Texas, in the northeast; from Uvalde County to Travis

County it parallels the Balcones fault zone at a distance of 10 to 15 miles. The zone coincides approximately with the outcrop of the Midway, or basal formation of the Eocene throughout its length. The faults are of all lengths up to 25 miles or more and the displacements, which are normal, range up to 600 feet. The faults are *en echelon* trending, however, at only a small angle to the trend of the zone. The downthrow of most of the faults is to the west or northwest, but in some of them the downthrow is to the east or southeast, and several pairs of faults form grabens. The faulting occurred long enough ago for the fault scarps to have been largely obliterated, and the faulting is therefore considerably older than the latest pronounced faulting in the Balcones zone, which is believed to have taken place in early Pliocene time. The zone is parallel to the strike of the Midway formation for nearly 500 miles and the faulting must have occurred between middle Eocene and late Miocene time.

The Upper Cretaceous strata in the area west of the Mexia-Powell fault zone, and between that zone and the Balcones escarpment, where the latter is present, have been broken by a multitude of minor faults, and by some faults of fairly large magnitude. Faults also occur in the Coastal Plain south and southeast of the Mexia-Powell zone, but they are somewhat scattered and their systematic arrangements are not so well known.

Notable structural features in the Texas Coastal Plain west of the Llano uplift are the San Antonio monoclinical nose, and the Culebra monoclinical nose, both of which plunge gently to the southwest; the Uvalde uplift, a broad complexly faulted upwarp; and the Picoso monoclinical fold, a subordinate fold plunging to the southeast in the axial part of the Rio Grande downwarp. All of these folds appear to be genetically connected with the Balcones fault zone.

The salt domes, of which 72 or more are known, form an interesting structural feature of Louisiana and Texas. A few of the domes manifest themselves clearly at the surface, but many of them lie completely buried and hidden. They consist of plugs of salt ranging in diameter from 1 mile to 3 miles or more, driven like nails in a plank, upward through thousands of feet of sediments, dragging with them or pushing ahead of them fragments of deeply buried formations. The salt is believed to have been squeezed upward through

points of structural weakness, by the weight of surrounding strata, from deeply buried masses of salt of Permian or perhaps of Trinity Cretaceous age.

The structural features of the Atlantic and Gulf Coastal Plain are somewhat more fully described and contrasted with the structural features in adjacent parts of Mexico in a paper by the writer recently transmitted for publication in the Bulletin of the Geological Society of America.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

THE LAVAS OF THE VOLCANO SUMACO, EASTERN ECUADOR, SOUTH AMERICA.

R. J. COLONY AND JOSEPH H. SINCLAIR.

INTRODUCTION.

In February, 1541, Gonzalo Pizarro, the brother of the famous conqueror of Peru, left Quito at the head of an expedition whose object was to conquer and explore the "land of cinnamon," a region reported to be situated at the east base of the Andes Mountains, and to be rich beyond belief not only in cinnamon, but in gold and other precious metals. The expedition ended in a disastrous return to Quito after many months of fruitless wandering in the rainy jungles of the headwaters of the Amazon River. It was not, however, a complete failure for Francisco Orellana, one of Pizarro's captains, becoming detached with a few companions from the main party in December, 1541, descended for the first time the Rio Napo to the Amazon and then the main stream to the Atlantic, thus accomplishing one of the great geographic feats of the sixteenth century.

According to historians¹ the members of the expedition of Pizarro made no stop of any length after leaving Quito till they came to a "Provincia" called "Zumaco, which is on the slopes of a high volcano"; here they stayed two months and in the record of their journey¹ is the first historical mention of the volcano Sumaco.

Statements regarding the volcano and its location have since then appeared from time to time² and Jimenez de la Espada describes the crater of the volcano as having a diameter of 100 meters. Some of the early explorers have mapped the volcano, but in no case is it correctly located on their maps,³

¹ Lopez de Gomara, Francisco, *Primera y Segunda Parte de la Historia General de las Indias*. Zaragoza, 1552. Chapter 143 of the "Primera Parte."

Zarata, Augustin de, *Historia del Descubrimiento y Conquista del Peru*. Antwerp, 1555. Book 4, chapter 2.

² Ordonez de Cevallos, Pedro, *Viage del Mundo*, Madrid, 1614.

Jimenez de la Espada, Marcos, *Primeros Descubrimientos del Pais de la Canela, El Centenario*, Madrid, 3, 437-457, 1892.

Rice, Alexander Hamilton, *From Quito to the Amazon via the Rio Napo*, *The Geog. Jour.*, 21, 401-418, 1903.

³ Maldo Nado, Pedro, *Carta de la Provincia de Quito*, 1750.

Diaz de la Fuente, Appolinario, *Mapa Geográfica de la Provincia Quixos*, 1777.

nor de Theodor Wolf (1892), Vacas Galindo or Fleming (1912) show it on their maps of Ecuador.

The geologists Joseph H. Sinclair and Theron Wasson, while descending the Rio Napo in 1921, and using Wolf's map of Ecuador, were naturally considerably surprised, when on September 9, 1921, at a point forty-four miles below the village of Napo, they noted thirty-one miles to the northwest a lofty, cone-shaped and isolated peak, rising high above the Amazon forests. From the traverse of the Rio Napo between

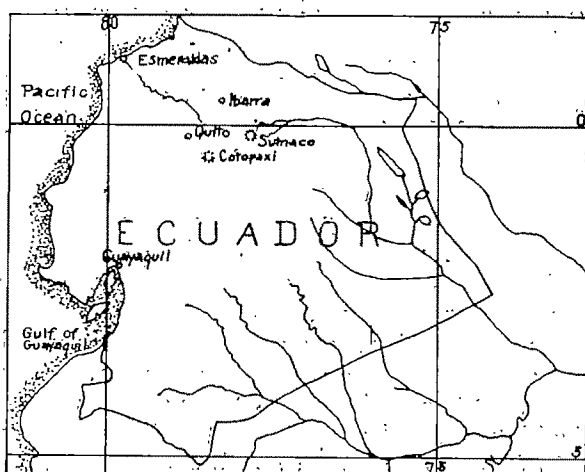


Fig. 1. Sketch map of Ecuador showing approximate location of Sumaco Volcano.

Napo and the mouth of the Rio Coca, and from a traverse from Napo north through Tena and Archidona to the base of the Guacamayos Range, the exact position of the volcano was found by intersections and its elevation by vertical angles, to be $0^{\circ}32'$ south latitude, $77^{\circ}38'$ west of Greenwich, and its highest point 12,670 feet above the sea.⁴ The location is shown approximately on the accompanying sketch map, Fig.

Humboldt, Alexander, *Atlas Géographique et physique des régions équinoxiales du nouveau continent*, Paris, 1814-1834, Plate XI.

Villavicencio, Manuel, *Carta Corográfica de la República del Ecuador*, New York, 1858.

⁴ Sinclair, J. H., and Wasson, T., *Explorations in Eastern Ecuador*, *The Geog. Review*, 13, 190-210, 1923.

1. In 1925 Commander George M. Dyott, while descending the Rio Napo, visited this mountain.⁵ (Fig. 2.)

On comparing the accounts of Jimenez de la Espada and Dyott, it seems probable that a period of volcanic activity occurred between 1865 and 1925, for Jimenez de la Espada describes the crater as being over 328 feet wide, while Dyott gives it a diameter of about 900 feet; and while the former describes a great opening in the crater to the south, Com-



Fig. 2. Photograph of volcano Sumaco, taken in 1925 by Commander George M. Dyott from the pueblo of San Jose, Eastern Ecuador.

mander Dyott states that the crater is perfectly formed. Unfortunately we have no comparative data on the depth of the crater.

THE LAVAS OF SUMACO.

Commander Dyott collected specimens at our request from Sumaco and thin sections were made of these. The petrographic examination of these thin sections has revealed that the magma of the volcano Sumaco is distinguished by the presence of feldspathoid minerals.

⁵ Dyott, G. M., *On the Trail of the Unknown in the Wilds of Ecuador and the Amazon*, New York, 1926.

The fact that the lavas of the volcanoes of Ecuador have been the subject of a great deal of petrographic study indicates that the Sumaco magma is unique in Ecuador, for these minerals could not have been overlooked in the numerous specimens of rocks examined, especially by German petrographers, from the volcanoes Cotopaxi, Pichincha, Tungurahua, etc.

According to Iddings⁶ the lavas of Ecuador are chiefly andesites, grading into basalts in some instances; in certain localities dacites and rhyolites are common, but Iddings does not mention the occurrence of any feldspathoid-bearing lavas, nor is any reference made to such lavas in the literature descriptive of the petrography of Ecuador rocks. Nephelite syenites are more or less common in Brazil, and they are mentioned as occurring in French Guiana and Patagonia. On the eastern flanks of the Andean ranges in Argentina and Patagonia nephelite-bearing lavas are associated with the usual Andean volcanics, and phonolites, nephelite-basalts, leucite-basalts and tephritic basalts occur in Brazil.⁷

The volcano of Sumaco differs from all other volcanic peaks of Ecuador in that it is isolated from the main range of the Andes, that it rises from a comparatively low elevation on the Amazon plain, and that it carries on its flanks uptilted sediments through which it has broken. From the description of the general geology of the region by Sinclair and Wasson⁸ it is clear that the volcano was born at a date subsequent to the deposition of the late Cretaceous strata around its base. Its uneroded condition indicates that it is of recent origin and the comparison above made of descriptions of the condition of the crater in 1865 and 1925 point to the possibility of activity between those dates.

Because this is the first petrographic description of any rocks from this volcano, which is the first volcanic center known east of the Andes in Ecuador, the following descriptions of the specimens collected by Commander Dyott are offered in detail. The observations are based on a petrographic study of nine thin sections cut from the specimens collected by Commander Dyott from the flanks of the volcano

⁶ Iddings, J. P., *Igneous Rocks*, Vol. II, p. 441.

⁷ Described in various papers by O. A. Derby, F. Graeff, E. Hussak, J. Machado, Hunter and H. Rosenbush, E. O. Hovey, F. E. Wright, References cited by J. P. Iddings, *Igneous Rocks*, Vol. II, p. 486.

⁸ Manuscript in the hands of the editor of the *Bulletin of the American Association of Petroleum Geologists*.

and from the rim of the crater, and on analyses of four of the lavas; the specimens collected were very small so that but little was left of each sample after the thin sections were cut. With the exception of No. 6, which is a foraminiferal limestone, all the rocks are andesitic and basaltic lavas. The striking thing is the presence of feldspathoids in all but one of the lavas. In this respect they differ from the usual Andean volcanics of Ecuador, since no feldspathoid-bearing lavas have been found in Ecuador, so far as the writers know. While in a general way all the specimens of the lavas are similar, there is sufficient difference between them to warrant individual descriptions, more especially since rocks of this character have never before been found in this locality.

Petrographic Description.

Specimen No. 1, from the rim of the crater on the summit of Sumaco, is a moderately strongly porphyritic tephrite carrying phenocrysts of plagioclase feldspar ranging from andesine to labradorite in composition, which exhibit a striking zonal development, complex twinning, and which contain zonally distributed inclusions. Pale green, very slightly pleochroic phenocrysts of augite are as plentifully distributed as are the plagioclase phenocrysts. The augite crystals are occasionally twinned; a few of them show the "hour-glass" structure and zonal development as well. In those sections showing the most marked pleochroism the color changes range from pale green to shades of yellowish green. Olivine is so very sparingly distributed that only one crystal was seen, associated with augite that occurs as a rim or border around it. The rock carries considerable magnetite in large and small grains, and a little accessory apatite that is strongly colored brown by what is judged to be finely disseminated magnetite dust. The groundmass is composed of minute augite prisms, small laths of plagioclase as well as slightly larger crystals of plagioclase that are much less calcic in composition than the large phenocrysts, with shells of alkalic feldspar around them; small crystals of orthoclase, little square and rectangular crystals that have the general appearance and habit of nephelite and imperfect dodecahedral crystals of haüynite showing strongly marked cleavage with inclusions oriented along the cleavages and distributed in fine dust-like particles that make some of the crystals almost opaque (Fig. 3). These crystals

of h  ynite are surrounded with a shell of isotropic substance that may possibly be of slightly different composition, and into which the cleavages do not usually extend. In addition there are altered turbid spots that seem in many places to be interstitial in their distribution; these may be altered sodalite, although the identification is doubtful. Megascopically the rock is moderately porphyritic, dark gray in color, with



Fig. 3. *Photomicrograph of Specimen No. 1. Ordinary light, $\times 54$.* Showing one of the h  ynite crystals, with cleavage, filled with fine, dark included matter. The character of the groundmass is shown a little more clearly at this higher magnification and the augite phenocrysts together with the clear plagioclase crystals may be readily seen.

abundant small phenocrysts of plagioclase and augite. A weathered exterior shell 1/16 inches thick surrounds the dark gray unweathered interior.

Specimen No. 2, taken from another part of the rim of the crater, is also a tephrite. The phenocrysts of plagioclase are more abundant than the augite; they have a decided fluxional arrangement and they are clear and fresh, complexly twinned

after the albite, pericline and Carlsbad laws and they exhibit zonal growth and contain crystal inclusions, glass inclusions and liquid and gas inclusions, all more or less well oriented. A few of the plagioclase crystals are slightly corroded, but resorption is not a prominent factor. Some of them are grouped so as to form compound phenocrysts and in some



Fig. 4. *Photomicrograph of Specimen No. 2. Ordinary light, $\times 100$.* The groundmass is a reddish glass, black in the picture, filled with little rectangular crystals, judged to be nephelite, and minute needles of plagioclase. Clear unaltered phenocrysts of plagioclase and augite are both shown in the field, and in the center of the picture a vesicle in clear colorless glass may be seen. An irregular patch of the same clear glass occurs in the lower right part of the photomicrograph.

cases the individual crystals in the groups are slightly separated from one another by brown interstitial glass (Fig. 4). Very faintly pleochroic, beautifully idiomorphic crystals of grayish-green augite constitute the prominent ferromagnesian component of the rock. These crystals have moderate birefringence ($N_\gamma - N_\alpha = \pm 0.020$), with maximum extinction

angles of 36° . They are optically positive, with notable dispersion, and occasional crystals exhibit very obscurely both the "hour-glass" structure and zonal structure. The groundmass is composed of a reddish-brown glassy base filled with multitudes of little square, rectangular and hexagonal crystals that resemble nephelinite, minute plagioclase laths, and a feldspathoid occurring in crystals that have a dodecahedral habit, in some of which cleavage is emphasized by oriented inclusions, whereas others exhibit the blue color characteristics of h  iynite; in addition there are other euhedral, clear isotropic crystals that resemble analcite. Olivine and apatite occur very sparingly, but magnetite is a prominent accessory. The rock is decidedly vesicular, the vesicles always occurring in clear, colorless transparent irregular isotropic areas that look like glass and that have an index of refraction as high as the plagioclase crystals. This specimen differs from No. 1 in that it is somewhat more feldspathic, shows flowage much more distinctly and carries more glass in the groundmass. The hand specimen of No. 2 is darker and considerably more vesicular than No. 1. The little plagioclase phenocrysts exhibit a directional arrangement due to flowage, and the h  iynite occurs in bluish crystals that are almost as large as some of the smaller feldspars. Both Nos. 1 and 2 have essentially the same chemical composition, as shown by the results of the chemical analyses, Table I.

Specimen Number 3, from the slopes of the volcano, is a vitrophyric tephrite whose groundmass is somewhat altered but whose phenocrysts are perfectly fresh, as are the tiny plagioclase microlites in the altered glassy groundmass. The rock is as vesicular as No. 2; the vesicles are always connected with and are distributed in colorless, isotropic, irregular areas of glass, similar to those in sample No. 2. The feldspar in this rock is confined to the groundmass through which it is distributed in the form of labradorite microlites. Pale, almost colorless augite, with moderate birefringence ($N_{\gamma}-N_{\alpha}=\pm 0.018$), moderately strong dispersion, optically positive character and with maximum extinction angles of 40° , is sparingly disseminated in idiomorphic crystals and groups of crystals. A feldspathoid with the habit of h  iynite is almost as abundant as the augite; the crystals are as large as the augite crystals and form one of the striking features of the rock. Most of them have good cleavage, some of the smaller ones carry oriented inclusions, and in a few instances they show

TABLE I.

	No. 1	No. 2	No. 3	No. 7
SiO ₂	52.88	51.74	46.14	50.90
Al ₂ O ₃	18.96	19.78	18.04	18.88
Fe ₂ O ₃	2.92	3.00	6.73	1.82
FeO	2.88	2.03	1.44	3.20
MgO	2.22	2.26	4.91	2.61
CaO	6.40	6.33	9.28	6.45
Na ₂ O	5.09	5.24	5.08	4.76
K ₂ O	4.05	3.74	2.91	3.13
H ₂ O—	0.85	0.75	0.24	1.48
H ₂ O+	1.33	1.54	0.66	1.80
TiO ₂	0.68	0.84	0.68	0.76
P ₂ O ₅	0.42	0.52	0.98	0.78
SO ₃	0.01	0.05	0.47	0.21
MnO	0.13	0.13	0.15	0.13
BaO	0.42	0.45	0.30	0.32
	99.24	98.40	98.01	97.23

Analyses by Ledoux and Company, New York City.

NORMS

	No. 1	No. 2	No. 3	No. 7
Or	23.91	22.24	17.24	18.35
Ab	30.39	30.39	14.67	34.58
An	16.96	19.18	19.46	21.68
Ne	6.82	7.67	13.63	2.27
S. S. ....	....	....	0.85	0.43
Di	10.50	7.78	16.63	5.40
Ol	1.81	1.47	3.22	5.20
Mt	4.18	4.41	3.02	2.55
Il	1.37	1.67	1.37	1.52
Hm .....	....	....	4.64	....
Ap	1.01	1.34	2.35	1.68

No. 1. Andesitic Tephrite, II, 5, 2, 4. Akerose; rim of crater.

No. 2. Andesitic Tephrite, II, 5, 2, 4. Akerose; rim of crater.

No. 3. Vitrophyric Tephrite, II, 6, 3, 4. Salemore; slopes of volcano.

No. 7. Andesitic Tephrite, II, 5, 3, 4. Andose; 2,000 feet down the slope.

resorption effects. These blue crystals are so abundant in the hand specimen that their index of refraction was determined in the powdered rock by the immersion method. A number of determinations gave an index of 1.503 ± 0.005 , corresponding to a somewhat calcic h  ynite. The index is higher than the indices given for h  ynite by Larsen⁹ and Iddings¹⁰. Larsen gives 1.496 as the index of refraction of h  ynite;

⁹ Larsen, E. S., The microscopic determination of the nonopaque minerals, Bull. 679, U. S. Geol. Surv., 1921.

¹⁰ Iddings, J. P., Rock Minerals.

Iddings gives 1.4961 as the index of blue haüynite from Niedermendig. Winchell¹¹ states that the index varies from 1.430 to 1.509, depending on the percentage of lime. A very small amount of magnetite, olivine and apatite occur as minor accessories, together with a strongly pleochroic light yellowish-brown hornblende.

This specimen differs from the other tephrites of this series in the presence of phenocrysts of haüynite instead of feldspar, in the restriction of feldspar to the groundmass, where it is distributed in the form of microscopic needles, and in the glassy character of the rock. The composition of the rock is likewise different as shown by the analysis, Table I. Silica is lower, lime and magnesia higher and sulphuric anhydride is higher. These differences are reflected in the mode of the rock. The rock is dark red-brown in color, somewhat vesicular, very fine in texture, and contains numerous small, blue crystals of haüynite ranging in size from 0.03 mm. to 1.00 mm., and larger phenocrysts of augite.

Specimen No. 4, also from the slopes of the volcano, is essentially an andesitic tephrite. It is porphyritic with a typical andesitic groundmass consisting of minute plagioclase laths of andesine make-up, arranged in characteristic flowage lines in a more or less isotropic base that is in part glass—the “hyalopilitic” structure exhibited by many andesites. The phenocrysts are large clear labradorite crystals that possess the usual complex twinning, large, pale augite crystals with a very moderate birefringence and brown basaltic hornblende, less plentiful than either the labradorite or the augite. Magnetite forms one of the prominent accessories, and apatite occurs in unusually large crystals that are more or less strongly colored violet-brown to smoky brown by included magnetite or ilmenite dust; in some places these inclusions are so concentrated as to render the crystal black and opaque in spots. Haüynite is distributed through the groundmass in clear, isotropic, small idiomorphic crystals that occasionally show a little resorption; the largest of these have dimensions of the magnitude of 0.25 mm. A few tiny square crystals doubtfully referred to nephelite are also scattered through the groundmass. The rock is slightly vesicular, and, like the other rocks of the series, the vesicles are commonly connected with irregular, clear, colorless isotropic areas that may be

¹¹ Winchell, N. H., and A. N., *Elements of Optical Mineralogy*, 1909.

common to all three of these rocks. In Nos. 7 and 9 it is slightly brownish in color, with very dark margins and pronounced cleavage in some instances (Fig. 5). The haidynite in No. 8 is not so plentiful; the color is pale blue, with deeper blue margins; even the brownish haidynite, especially in No. 7, is occasionally slightly bluish in the centers. Unusually large crystals of brown apatite form very striking accessories in all three of these rocks, and magnetite is a prominent component.

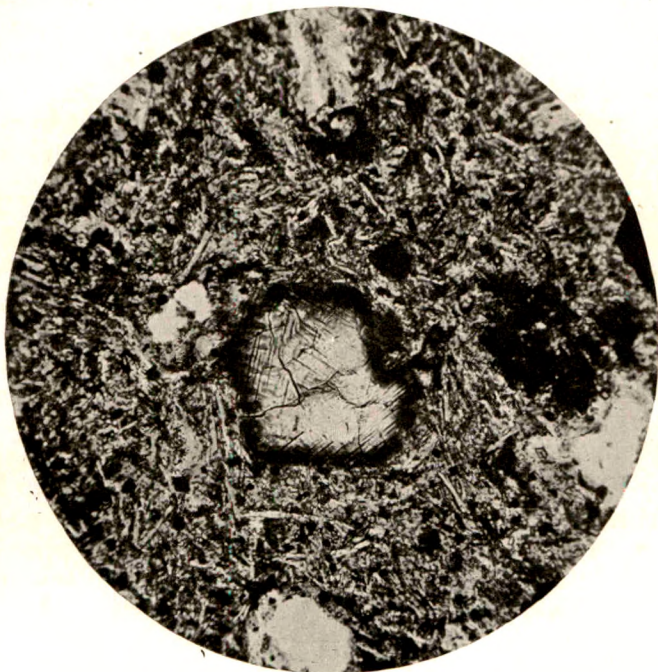


Fig. 5. *Photomicrograph of Specimen No. 7. Ordinary light, $\times 100$.* Taken at the higher magnification of 100 diameters in order to show the details of one of the haidynite crystals, with its very dark margin, and incompletely developed cleavage. The character of the groundmass is a little more plainly exhibited, also.

Megascopically No. 7 is moderately porphyritic, very fine textured as to groundmass, dark gray in color, with phenocrysts of plagioclase up to a centimeter in length, and of augite ranging in size to 7 mm. as a maximum. No. 8 is essentially the same as No. 7, but the augite is not so prominent. No. 9 is similar to Nos. 7 and 8. As may be seen from the chemical analyses, No. 7 is strikingly similar in compositions to Nos. 1 and 2.

Comment on Analyses.

The chemical analyses, Table I, of Nos. 1, 2 and 7 are similar, but No. 3 has lower silica, higher lime, higher magnesia and higher combined iron oxides. The total alkali in Nos. 1 and 2 is about the same, nine percent approximately, whereas in Nos. 3 and 7 the total alkali is about eight percent. In other respects Nos. 1, 2 and 7 are nearly alike in composition, especially in their content of lime, magnesia, alumina and approximately of silica and total iron oxides. All of the rocks carry a little sulphuric anhydride which, together with the high alkali, the lime and alumina, is reflected in their mineralogy by the presence of the feldspathoid haüynite and by the probable presence of nephelite as the minute crystals mentioned in the description of these rocks. Potash is higher than usual in rocks of this general composition, occurring in part as shells or coatings of orthoclase on some of the plagioclase phenocrysts, in part as little crystals of orthoclase distributed through the glassy base of the rocks, and probably in part in "occult" form in the glassy base. Nos. 1, 2, and 7 are andesitic, whereas No. 3 is basaltic. According to the Quantitative System nephelite occurs in the norm of all four of the rocks, with olivine and diopside. The prominent feldspathoid in the mode is haüynite, with nephelite of less certain identification.

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KANSAS PERMIAN INSECTS. PART II. ORDER
PROTOPERLARIA: FAMILY LEMMATO-
PHORIDAE (Continued).

R. J. TILLYARD.

[Studies aided by a grant from the Marsh Fund of the National Academy of Sciences.]

Since writing the previous part, which dealt with the genus *Lemmatophora* Sell. alone, I have been fortunate in receiving from Mr. F. M. Carpenter of the Bussey Institution, Harvard University, a series of photographs taken by him of some of Sellards' type specimens of the family Lemmatophoridae. In the genus *Lemmatophora*, Mr. Carpenter sent me photographs of the types of *L. hirsuta* Sell. (Sellards' No. 1047), *L. delicosa* Sell. (Sellards' No. 1050), *L. elongata* Sell. (Sellards' No. 149) and *L. anomala* Sell. (Sellards' No. 1089). A study of these photographs shows that the conclusions reached by me in Part 10 are correct, viz., that Sellards' species *L. hirsuta*, *L. delicosa* and *L. elongata* are all synonymous with his *L. typica*. The following further conclusions may also be made from the photographs:

(1) *L. anomala* Sell. is merely a peculiar aberrancy of *L. typica* Sell., a possibility already suggested by me when dealing with this species in Part 10. Sellards described the type as having one branch of the media coalesced for a short distance with the cubitus. This branch could only have been MP_2 . The photograph of the type shows that MP_2 and Cu_1 are both bent out of their normal courses and just meet one another at a single point; they fuse for an instant only, and then diverge again to the wing-margin, so as to form a "chiasma" (a figure in the form of the Greek letter "chi" or the Roman "X"). It is incorrect to call this "a fusion for a short distance," for a study of the photograph under a lens shows that the two veins do not fuse at all; they barely touch one another, and there is even the slightest suggestion of a very minute cross-vein joining them together. The stages bringing about this formation from the typical one are very simple, and are almost exactly paralleled in the case of the fusion of Rs with MA in *Paraprisca* (Fig. 14, C, B).

Hence we may now place *L. anomala* Sell. definitely as a further synonym of *L. typica* Sell.

(2) *L. delicosa* Sell. The extra branch of MP_2 which, according to Sellards, distinguishes this species from *L. typica* Sell., turns out, on an examination of the photograph of the type specimen, to be a small terminal fork of about one-fourth the length of the normal fork of MP , and with its additional (posterior) branch very weakly formed. Such a small additional fork might be found almost anywhere, and one wonders why Sellards took notice of this particular one, when he ignored so many other equally insignificant variations.

(3) *L. elongata* Sell. The photograph discloses *the basal half only* of the forewing of what is clearly a rather large specimen of *L. typica*. There is nothing in this specimen (Sellards' No. 149) to justify the name *elongata*, but rather the reverse, for the wing appears quite as broad as usual, if not a little broader. But Sellards gives the measurement of the complete wing as 9 mm. long. I do not understand this, unless the type has got broken since Sellards described it; in which case, the apical portion appears to be lost.

Having finally disposed of the genus *Lemmatophora* itself, let us now turn to the other genera which may legitimately be included in the family Lemmatophoridae. For this purpose, we must pass under review all which show the wing-like prothoracic expansions, even if proportionately smaller than in *Lemmatophora* itself. These are the Sellardsian genera *Artinska*, *Estadia*, *Lectrum*, *Prosaïtes*, *Prisca* (now *Paraprisca* Handl.), *Lecorium*, *Orta* and *Stemma*. Sellards separates the last two off and places them in another family "Ortidae" (*sic*), more correctly Ortidae, from the type-genus *Orta*. But we shall see that the character relied on for the definition of this family is, like many other venational characters in this group, a variable within the limits of a single species, so that, for instance, some individuals of the species *Orta ovata* Sell. classify into the family Ortidae (as they obviously ought to do) and others go into the genus *Artinska* Sell., and therefore also into the family Lemmatophoridae! The only remedy, of course, is to drop the family Ortidae, which is no family at all, and take all these genera into the family Lemmatophoridae.

The same kind of variation which is fatal to Sellards' family Ortidae is also fatal to some of his genera, and even more so to his species. In the group of genera, *Artinska-Estadia-Lectrum*, Sellards figures *Artinska clara* Sell. (1909, p. 164, Fig. 25), *Estadia elongata* Sell. (l. c., Fig. 15) and *Lectrum anomalum* Sell. (l. c., Fig. 28). Mr. Carpenter has kindly also

sent me photographs of the types of the following species: *A. medialis* Sell. (Sellards' No. 1381), *A. gracilis* Sell. (Sellards' No. 1090), *A. pecta* Sell. (Sellards' No. 1087), *A. major* Sell. (Sellards' No. 1375) and *E. arcuata* Sell. (Sellards' No. 412). These photographs only serve to confirm the conclusion to which I had already come from a study of Sellards' descriptions and figures of these species and a comparison of them with the characters exhibited in the long series of specimens present in the Yale University Collection, viz., that *not only are the three genera Artinska, Estadia and Lectrum a single genus, but the ten Sellardsian species included in them are only a single species.*

Mr. Carpenter spent some time searching for other types in the Sellards Collection, but could not find them. The missing types include those of *Artinska extensa* Sell., *Estadia tenuis* Sell., and all the described species of *Prosaïtes*, *Paraprisca*, *Lecorium* and *Urba*. This is very unfortunate in the case of the genera *Prosaïtes* and *Urba*, for these were not figured by Sellards, and the descriptions are short and vague in the extreme. One would also have liked to see the type of *Lecorium* (*L. elongatum* Sell.) which is placed by him at the end of his family Lemmatophoridae, but in which his figure (l. c., Fig. 26) shows a strong union basally between M and Cu, this union being, in his own words, "the special peculiarity" of the family Ortidae.

Reviewing the large number of specimens belonging to this family, one gets a strong impression of a group of primitive insects undergoing very rapid evolution through extensive individual variation. In attempting to subdivide such a group into genera and species, one has to ignore the great mass of fluctuating characters as far as possible, and try to pick out and fix one's attention on those few which stand out as landmarks in the general welter of variability. If one does this, there will emerge, pretty clearly, three ways of subdividing the mass, as follows:

(1) One group of forms can be picked out in which Rs is always simple; another in which it is always branched. The typical genus for the former is *Lemmatophora* Sell., for the latter *Artinska* Sell.

(2) One group of forms has a robust forewing of comparatively greater breadth; another group has a more elongated forewing, markedly narrower in proportion to its length. *Lemmatophora* Sell. and *Artinska* Sell. are both typical of the

former, *Paraprisca* Handl. (= *Prisca* Sell.), *Lecorium* Sell. and *Stemma* Sell. of the latter.

(3) After removal of the more slender forms (*Paraprisca-Stemma* group) there still remain, among the robust forewing types, a comparatively large and strongly individualized species in each genus (this species being the dominant one in each case) and one or more smaller and less striking forms, not dominant. These latter should be kept simply as species within each genus having the dominant species for genotype, as has already been done with the genus *Lemmatophora* Sell. in Part 10.

Having made these divisions, we may now turn for a moment to the variable characters which have been used indiscriminately by Sellards in making his generic and specific subdivisions. These are none the less interesting for being so unstable. We may classify them as follows:

(1) *Variations in the branchings of Rs*.—Apart from the division into forms having a simple Rs and a clearly forked Rs (this division, apart from occasional small terminal forkings, being a generic constant), we find a great diversity in the size of the fork, when present, and also in the presence or absence of additional terminal forks; these latter are chiefly developed on the anterior branch. The extra forks have no specific value.

(2) *Variations in the branchings of M*.—In the dominant robust forms, these variations run to extremes; either MA or MP or both may be simple, or two-branched, or three-branched, and the size of each fork varies from specimen to specimen. In the smaller robust forms, and also in the slender forms, it is a general rule for MA to remain simple, while MP is either two- or three-branched.

(3) *Variations in the branchings of Cu₁*.—In studying these, it should be noted that Sellards' "Cu₂" is the most basal branch of Cu₁, here called Cu_{1c}. The normal formation of Cu₁ is the same throughout the family, viz., a triple fork of very characteristic form (see Figs. 3, 4, 9) into three branches Cu_{1a}, Cu_{1b} and Cu_{1c}. Any one of these three branches may develop occasionally an extra terminal fork. Further, an extra branch may develop about midway along the common stem of Cu_{1a} and Cu_{1b} and may fuse with Cu_{1c}, thus making this vein appear distally forked (Fig. 6). This gives the condition made diagnostic for the genus *Lectrum* by Sellards in the words "Cu₂ is forked, differing in this respect from all other genera of the family."

Variations in the form of Cu_1 may not only take the above shapes, by addition of extra branches, but there is also, occasionally, an apparent *reduction* to a two-branched condition, which Sellards uses to characterize his genus *Prosaites* (l. c., p. 167). Specimens showing this condition (Fig. 21) are rare, and I have only found five such forewings in the whole of the Yale University Collection. A careful examination of these wings shows that Cu_1 is *in reality still three-branched*, the branch Cu_{1a} having become attached secondarily to MP. The proof of this lies in the thickness and convexity of this vein, which are retained in spite of its attachment to the slender, concave vein MP. Some intermediates between this form and the normal three-branched form also occur, and there can be no doubt that the character is not of the generic value which Sellards imagined it to be; nor, indeed, is it even of specific value either.

The genus *Prosaites* Sell. presents altogether a special problem which must be left to be dealt with in that part of this paper which attempts an analysis of the *Lecorium-Stemma* group.

A point which adds somewhat to the general difficulty of study of these forms is that Sellards selected for his types, in certain cases, abnormal forms having an extra small apical fork on one or other of their main veins. The type of *Lecorium elongatum* Sell., for example, has such a small fork at the end of R_s ; yet it is clear, from a study of a series of examples, that this was an exceptional individual peculiarity, and should not have been taken into consideration in defining the genus. The type of *Stemma elegans* Sell. likewise has a small extra fork at the end of Cu_{1b} ; but this does not bring it into line with the normal types having Cu_{1b} three-branched, for the true Cu_{1a} is evidently attached to MP.

(4) *Variation in the anal veins*.—Normally 1A and 2A are two strong, convex veins, diverging markedly distally, and united by a series of strong cross-veins placed obliquely between them. Variations from this type consist either in the development of small terminal forks on one or both veins, or a strong intermediate fork attached to one or the other, or the formation of deep, narrow forks from near the base; in this last case, the extra veins are usually delicate and thinly chitinated. The shape of the anal angle is also very variable, being sometimes clear-cut and sometimes more or less rounded. As the anal venation varies from individual to individual, with no clearly

marked types, and as many specimens have the whole area missing, I have not used these veins to any extent in making my subdivisions.

(5) *Variations in the relationship of Rs to MA*:—We have already seen (Part 10) that the genus *Lisca* Sell. is merely an aberration from *Lemmatophora* Sell. in which Rs is fused with MA for a short distance, instead of being, as normally, free. This condition of fusion is never found in the genotype *Lemmatophora typica* Sell., and only very occasionally in *L. minuta* (Sell.). When, however, we turn to the other groups, we find this type of variation most marked (Fig. 5). Sellards made it the basis of his separation of *Estadia* Sell. from *Artinska* Sell., though, if he had studied carefully a large series of forms such as he probably possesses in these genera, he should have found all the connecting links shown in Fig. 5, and should have been struck with the fact that they all belonged to a single species. In the slender-winged forms, Sellards selected for his type of the genus *Prisca* Sell. (now *Paraprisca* Handl.) a specimen with Rs partially fused with MA, and includes this in his generic characters (if it can be said that a genus is characterized at all, when genus and species are treated together in three lines of print, without any indication of which are generic and which specific characters). But, again, careful searching amongst his two thousand specimens should have shown him just as many specimens of this species without the fusion as there were with it. In the *Stemma* group, where the tendency to fusion is at a maximum, the majority of the specimens show more or less fusion of Rs with MA.

(6) *Variation in the relationship of M to Cu*:—Apart from the anomaly shown in *Lemmatophora anomala* Sell., M and Cu keep their normal relationship throughout the *Lemmatophora* group of species. This is also true for the robust-winged forms included in Sellards' group *Artinska-Estadia-Lectrum*. In the slender-winged species, however, as might be expected, the tendency to fusion between the more basal portions of these two veins is very highly developed. In *Lecorium* Sell. and *Stemma* Sell. it appears to have become a fixed character, and may legitimately be used in defining the genera. Apart from the *Lemmatophora* group, there is another group of small to medium, non-dominant forms present in the collection with a forked Rs, and represented by Sellards' genus *Orta*. Specimens of these are very common in the Yale University

Collection, and I was astonished to find that about as many of them have the normal condition of Cu and M quite free basally as have them fused. One can take two specimens of Sellards' *Orta ovata*, obviously belonging to the same species, and one of them goes into the genus *Orta* Sell., the other into *Artinska* Sell.! The only difference is this condition of Cu and M. *Orta* Sell. must therefore be suppressed as a synonym of *Artinska* Sell., and with it goes the family Ortidae.

(7) *Variation in shape of wing*:—The variation in the form of the anal angle has already been noted. An equally noticeable variation occurs in the form of the apex, which may be broadly rounded, or less so, or even tending to be slightly but very obtusely pointed. The variations in the shape of the wing appear to parallel very closely those that can be found in a series of the recent archaic New Zealand stone-fly *Austroperla cyrene* Newm.

(8) *Variation in color-pattern*:—Nowhere in his descriptions does Sellards pay any attention to the color-pattern of the forewing. Yet this is remarkably well preserved in most specimens, and, in one group at least, supplies the key to the whole situation. We have already seen how, in *Lemmatorphora typica* Sell., there is a color-pattern distinguished particularly by the presence of a strongly marked, more or less squarish patch of dark pigment covering the basal fork of Cu₁ and running upward to M. This patch can be seen in the type-specimens of *L. hirsuta* Sell., *L. delicosa* Sell., *L. elongata* Sell. and *L. anomala* Sell. (partly obliterated by a roughness of the rock surface in this last). Consideration of this circumstance should have suggested that it was not very likely that four really distinct species would have the same color-pattern. But when we come to study the *Artinska-Estadia-Lectrum* group of Sellards, we find that *every single specimen of all the ten species of these three alleged genera have the same very striking color-pattern in the forewing*, viz., three large, dark, irregular blotches of pigment, placed, one covering the two main branches of Cu₁ somewhat distad from the fork, a second near the middle of the wing, overlying Rs and MA, and a third distally, stretching more or less from Rs to MP. Besides these, the basal portion of R for close on 2 mm. is very darkly pigmented also. The areas and shapes of these four pigment patches vary from specimen to specimen, but the four patches are always there. To me, it is inconceivable that such a striking specific character as this color-pattern should run

through three or four genera and numerous species, especially as it is always associated with the robust wing-form, with large size, and with another equally striking character, viz., the arched subcosta. It was the combination of these two characters that first led me to doubt the value of Sellards' generic and specific characters in this group. Also, I quite fail to understand how Sellards omitted to mention these outstanding color-markings in his descriptions.

It is clear, from all the above considerations, that we really have to deal with a group consisting of far fewer genera and species than Sellards proposed for it. Including the genus *Lemmatophora* Sell., already dealt with in Part 10, the family

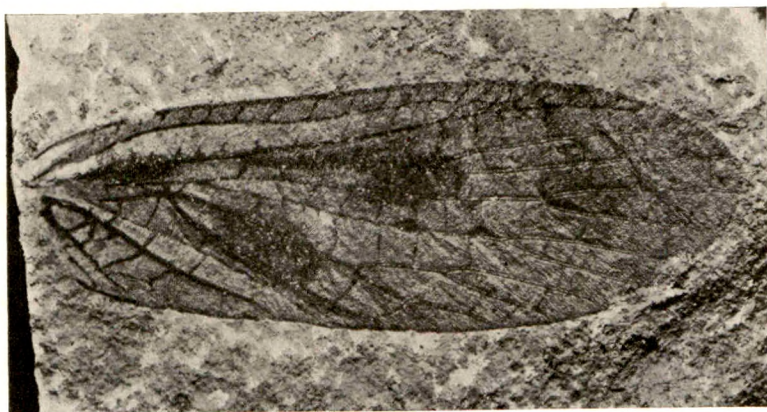


Fig. 1. *Artinska clara* Sell. Specimen No. 5263. Forewing, length 10.8 mm. Normal *Artinska*-form, with Rs and MA separate. Apex of wing to right in this and all succeeding figures. Photo. by W. C. Davies.

may now be divided up into genera according to the following key:

1. Rs simple, or very rarely with a small apical fork. 2.
Rs with a well-developed fork; more rarely, three-branched. 4.
2. Comparatively broad forewings, the ratio of length to breadth being at most 3:1; partial fusion of Rs with MA exceedingly rare; basal fusion of M with Cu₁ never present. Genus *Lemmatophora* Sell.
Comparatively narrow forewings, the ratio of length to breadth being always greater than 3:1, usually about 7:2; partial fusion of Rs with MA and basal fusion of M with Cu₁ either present or absent. 3.
3. M and Cu₁ free from one another entirely. ...Genus *Paraprisca* Handl.
M and Cu₁ fused close to base, in such a way that the two main branches of Cu₁ appear to arise separately from M. Genus *Lecorium* Sell.
4. Comparatively broad forewings, the ratio of length to breadth being at

most 3:1; basal fusion of M with Cu₁ sometimes present in the smaller species only. Genus *Artinska* Sell.
 Comparatively narrow forewings, the ratio of length to breadth being always greater than 3:1, usually about 7:2; basal fusion of M with Cu₁ present. Genus *Sellardsia*, n. gen.

Genus *Artinska* Sell.

(Figs. 1-12.)

Artinska Sellards, 1909, p. 163 (Genotype, *A. clara* Sell., by priority of position).

Estadia Sellards, 1909, p. 166 (Genotype, *E. elongata* Sell., by priority of position).

Lectrum Sellards, 1909, p. 167 (Genotype, *L. anomalum* Sell., the only species).

Orta Sellards, 1909, p. 168 (Genotype, *Orta ovata* Sell., the only species).

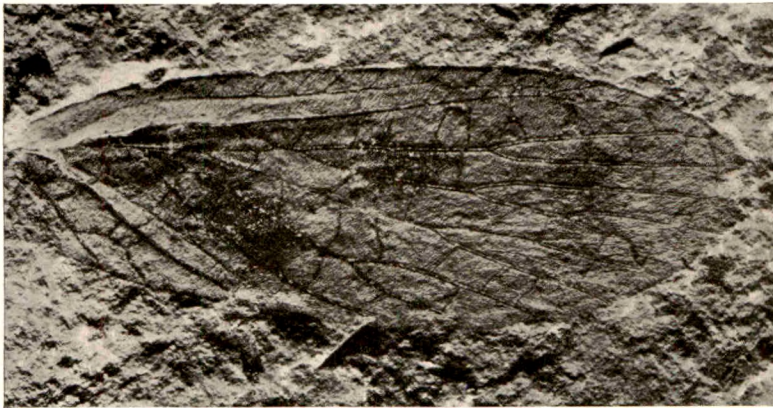


Fig. 2. *Artinska clara* Sell. Specimen No. 5264. Forewing, length 10.8 mm. *Estadia*-form, with Rs and MA fused for a short space. Photo. by W. C. Davies.

Characters.—*Forewing* comparatively broad and well rounded in shape, the ratio of length to breadth seldom as much as 3:1. Sc long but variable in form. R very strongly formed. Rs always with a well-developed fork. MA very variable, simple or forked, sometimes free, sometimes fused for a short distance with Rs near origin. MP variable, forked. Cu₁ with three branches normally, sometimes four or five. Anal veins two in number, convex, strongly formed, normally simple, more rarely branched or forked. *Hindwing* with Sc long, R long and well formed, Rs forked, either free or fused basally for a space with MA; MA and MP variable, forked or

simple; Cu₁ forked; 2A with numerous branches, the first of which is forked. *Prothoracic lobes* moderately well developed. General build of insect robust.

Genotype.—*Artinska clara* Sell.

Horizon.—Lower Permian of Kansas.

KEY TO THE SPECIES OF ARTINSKA SELL.

1. Large species, forewings 8 to 12 mm. in length. 2.
Smaller species, forewings 7 mm. long or less.*A. ovata* (Sell.)
2. Sc strongly arched near base, R straight; basal portion of R deeply pigmented, and three large patches of dark pigment on forewing, one covering the branches of Cu₁ not far from fork, one near middle of wing covering Rs and MA and a third more distally placed between Rs and MP.*A. clara* Sell.
Sc nearly straight, R slightly bent at origin of Rs; coloration of forewing not as above, the only pigmentation being along a few cross-veins and a moderately strong patch at about two-thirds of wing-length, between lower branch of Rs and upper branch of MP.

A. sellardsi, n. sp.

Artinska clara Sell.

(Figs. 1-7.)

- Artinska clara* Sell., 1909, p. 165 and Fig. 25.
Artinska medialis Sell., 1909, p. 165.
Artinska gracilis Sell., 1909, p. 165.
Artinska pecta Sell., 1909, p. 165.
Artinska major Sell., 1909, p. 166.
Artinska extensa Sell., 1909, p. 166 and Fig. 15.
Estadia elongata Sell., 1909, p. 166.
Estadia arcuata Sell., 1909, p. 166.
Estadia tenuis Sell., 1909, p. 166.
Lectrum anomalum Sell., 1909, p. 167 and Fig. 28.

This robustly built species is one of the commonest insects in the whole collection, there being more than sixty specimens recognizable as belonging to it, with about forty counterparts. Most of these are forewings, some of which are very completely preserved, with almost every hair on the wing still present and the color-pattern very strongly marked.

There cannot be a shadow of a doubt that the three genera *Artinska* Sell., *Estadia* Sell. and *Lectrum* Sell. are synonymous, and that the ten species allocated between them by Sellards are one and the same species, which must take, by priority, the name *Artinska clara* Sell. Sellards' collection must have contained between fifty and a hundred specimens belonging to this species.

In order to exhibit the great range of variability in this species, I have taken Sellards' ten types and divided them on

the condition of the veins Rs, MA, MP and Cu_1 in the forewing, treating each type as a venational "variety" on the forking of the veins. A fork is counted unless it happens to be a very small apical fork, in which case only a score of $\frac{1}{2}$ is allowed for it. I have then compared with these a series of twenty-two complete or nearly complete forewings in very good condition, from the Yale University Collection, and have divided these up amongst the Sellardsian types as far as they

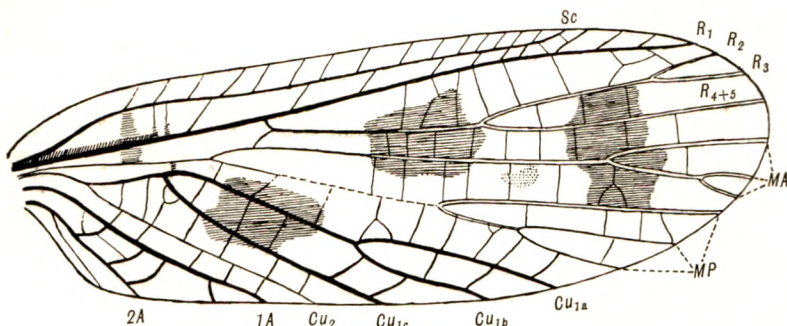


Fig. 3. *Artinska clara* Sell. Specimen No. 5265. Forewing, length 10.9 mm. Normal *Artinska*-form, with Rs and MA separate.

will go, ignoring small terminal forks in placing them. Specimens in the Sellards Collection have their numbers prefixed by "S." The following table gives the results:

Table of Venational Varieties in Artinska clara Sell.

No.	Group	Variety	Number of branches of			
			Rs	MA	MP	Cu_1
S. 115	<i>Artinska</i> Sell. (Rs and MA free)	<i>clara</i> Sell.	2	1	2	3
5287	"	new variety	2	2	1	4
S. 1381	"	<i>medialis</i> Sell.	2	2½	2	3
1003	"	"	2	2	2	3
5289	"	"	2	2	2	3
5292	"	"	2	2	2	3
5293	"	"	2	2	2	3
5294	"	"	2	2	2	3
S. 1087	"	<i>pecta</i> Sell.	2	3	2	3
S. 1090	"	<i>gracilis</i> Sell.	2	2	2	4
5263	"	new variety	2	2	2	5
S. 28	"	<i>extensa</i> Sell.	2	3	1	4
5265	"	new variety	3	2	3	3
5290	"	"	3	2	3	3
5286	"	"	3	2	2	3
S. 1375	"	<i>major</i> Sell.	4	2	2	4

No.	Group	Variety	Number of branches of			
			Rs	MA	MP	Cu ₁
S. 412	<i>Estadia</i> Sell. (Rs and MA fused)	<i>arcuata</i> Sell.	2	2	2	3
S. 1112	" "	<i>elongata</i> Sell.	2	2	2	3
S. 1382	" "	<i>tenuis</i> Sell.	2(?)	1	2	3
5298	" "	" "	2	2	2	3
5303	" "	" "	2	2	2	3
5305	" "	new variety	2	2	1	3½
5264	" "	" "	2½	3	2	3
5296	" "	" "	3	1	1	3½
5297	" "	" "	3	1	2	3
5299	" "	" "	3	1	2	3
5295	" "	" "	3	1	2	4
5302	" "	" "	3	2	3	3
5304	" "	" "	3	2	3	4
S. 173	<i>Lectrum</i> Sell. (special formation of Cu ₁)	<i>anomalum</i> Sell.	?	?	?	4
5306	" "	" "	2	2	1	4
5300	" "	new variety	2	2	1	5

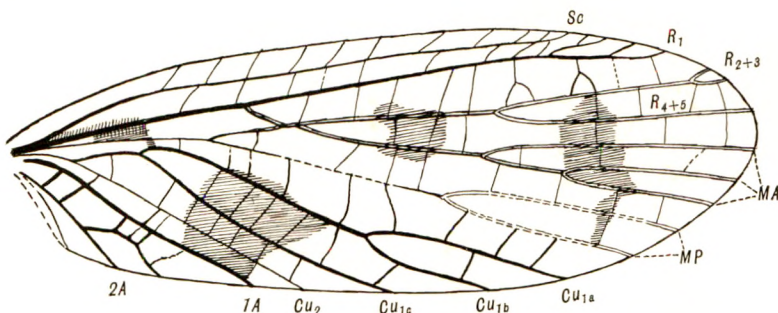


Fig. 4. *Artinska clara* Sell. Specimen No. 5264. Forewing, length 10.8 mm. *Estadia*-form, with Rs and MA fused for a short space.

An analysis of the above table shows that, *exclusive of all other venational variations than the mere number of the forks of these four veins*, these thirty-two specimens are divisible into *twenty-two* varieties, each of which, on Sellards' view, is a species. Sellards himself named ten such out of fourteen specimens studied, which is about the same proportion. I do not propose to add to the burden by giving names to the remainder of these varieties. It is evident that the examples given in the table are only a fraction of the possible combinations that would be found if we had access to a large number of complete forewings; as there are three possible forms of Rs, three of MA, three of MP and three of Cu₁, the total number of varieties that *might* occur, on a combination of these four characters alone, is $3 \times 3 \times 3 \times 3 = 81$!

The abundance of different types, taken by itself, is, however, no justification for the suppression of genera and species. I have already mentioned the unity of color-pattern running right through the series. I must also stress the fact that the subcosta is of very characteristic form throughout, being markedly arched at the base, and ending more or less inconclusively distally through cross-vein connections with the veinlets of the pterostigmatic region. But the most telling argument against the validity of the Sellardsian genera can be pre-

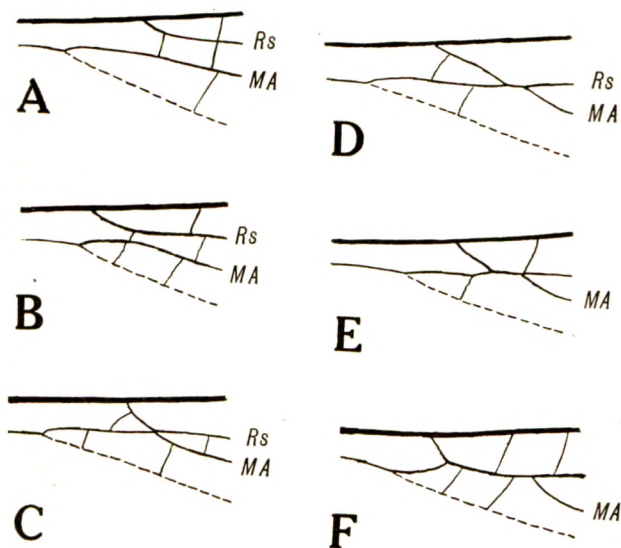


Fig. 5. Stages in the evolution of the *Estadia*-form of *Artinska clara* Sell. from the normal *Artinska*-form. A, normal form, from Specimen No. 5287. B, Rs and MA approaching, from Specimen No. 5290. C, Rs and MA touching, from Specimen No. 5304. D, Slight fusion between Rs and MA (*Estadia*-form), from Specimen No. 5302. E, medium fusion between Rs and MA (*Estadia*-form), from Specimen No. 5264. F, long fusion between Rs and MA (*Estadia*-form), from Specimen No. 5299.

sented in the form of a series of intermediate forms. In Fig. 5, six stages are shown in the transformation of *Artinska* to *Estadia*. Fig. 5, A, from Specimen No. 5287, is the typical condition of the basal portions of Rs and MA within the species *Artinska clara* Sell. (*sens. lat.*). In Fig. 5, B, taken from Specimen No. 5290, we see a closer approach between the two veins, so that the distance separating them is about half that in the normal form. Both the above, on Sellards' classification, would go into *Artinska*. In Fig. 5, C, taken from Specimen

5304, MA is angulated and just touching Rs at a single point; it represents the passage of *Artinska* over to *Estadia*. Fig. 5, D, from Specimen No. 5302, is definitely of the *Estadia* type, but with a very small amount of fusion between Rs and MA. In Figs. 5, E, F, the amount of fusion becomes progressively larger, Fig. 5, E, from Specimen No. 5264, being a very common form, while Fig. 5, F, from Specimen No. 5299, is somewhat less usual.

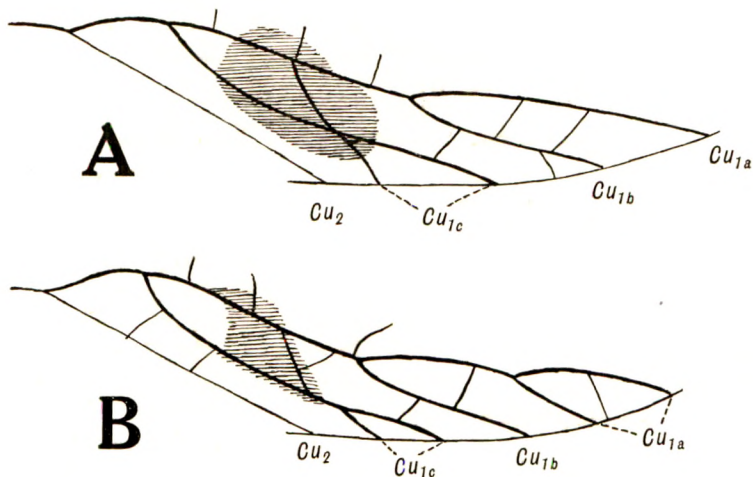


Fig. 6. *Artinska clara* Sell. Two examples of the *Lectrum*-form of Cu₁. A, from Specimen No. 5306. B, from Specimen No. 5300.

An analysis of fifty-one complete or nearly complete forewings of *Artinska clara* showing well-preserved venation and color-pattern gives the following result:

Number definitely of *Artinska* type: 31.

Number intermediate between *Artinska* and *Estadia* (Fig. 5, C): 1.

Number definitely of *Estadia* type: 19.

Figs. 2-5 present the two main types for comparison. Even without figures of the innumerable other varieties here studied, I think this should suffice to prove the unity of the species.

In the case of *Lectrum* Sell., only a single type, *L. anomalum* Sell., based on a single specimen, was described by Sellards. The selection of the specific name indicates that the author recognized in his mind the anomalous condition of the vena-

tion on which he based his genus. Two specimens in the Yale University Collection fall within the *Lectrum* type, viz., No. 5306 (Fig. 6, A) and No. 5300 (Fig. 6, B). The presence of the large, dark blotch, characteristic of the species *A. clara* Sell., covering portions of the two main branches of Cu_1 , is likely to hide from the cursory examiner the aberrant extra branch descending from the anterior branch to the posterior and reinforcing Cu_{1c} by partial fusion with it, making that vein appear to be distally forked. It is this condition which is described by Sellards as " Cu_2 is forked, differing in this respect from all other genera of the family." Sellards' figure of *Lectrum anomalum* (l. c., Fig. 28) shows clearly that his Cu_2 is in reality Cu_{1c} .

Another point of interest is that Sellards' specimen No. 173, the type of *L. anomalum*, would otherwise classify as an *Artinska*, Rs and MP being quite separate (though his figure also shows a slight fusion basally between M and Cu , suggesting that he ought to have placed it in his family Ortidae). The two specimens shown in Fig. 6, however, classify into *Estadia*, owing to fusion of Rs with MA for a short distance—surely a further proof of the essential unity of the three genera.

It being admitted that the three Sellardsian genera are synonymous, the unity of the ten species described by him follows at once on the essential similarity of all the forms concerned in everything except the variable characters of the venation; more particularly, their unity in color-pattern and in the strongly arched subcosta. It only remains to give a detailed description of the species, which must take, by priority, the name *Artinska clara* Sell.:

Total length of body 8.5 mm. (Specimen No. 5288, apparently considerably shrunken) to 11 mm. (Specimen No. 5285); *antennae* about 3 mm., *cerci* about 4.5 mm.

General build very robust, with *head* somewhat wider than long, rather small; *thorax* very stout and deep, *abdomen* rather stout; general coloring dark fuscous or brown. *Legs* stout, rather short; hind femur 2.5 mm., hind tibia 1.8 mm., with a stiff, projecting bristle or spine about half-way along the outer border; (tarsi incomplete). *Cerci* stout at base, tapering strongly, unicolorous.

Forewing:—*Length* 10.5 up to 12.5 mm., *greatest breadth* 3.8 to 4.4 mm., *ratio of length to breadth* 2.8–2.9:1. Wing broadly oval in shape, the apex more or less broadly rounded, the costal and posterior margins about equally convex, the anal

angle either rounded or obtusely angulate. Sc a strong vein, markedly arched in its basal half, and reaching well beyond half-way along wing, when its distal end becomes more or less indistinct through fusions with the more basally placed of the pterostigmatic veinlets, by means of short, connecting cross-veins. R a very stout vein, strongly pigmented from base nearly to origin of Rs; this dark pigment usually lies as a narrow band along the vein, but sometimes passes down to meet M or even Cu₁. R₁ slightly curved distally, ending well before apex; pterostigmatic area long, not chitinated, but well

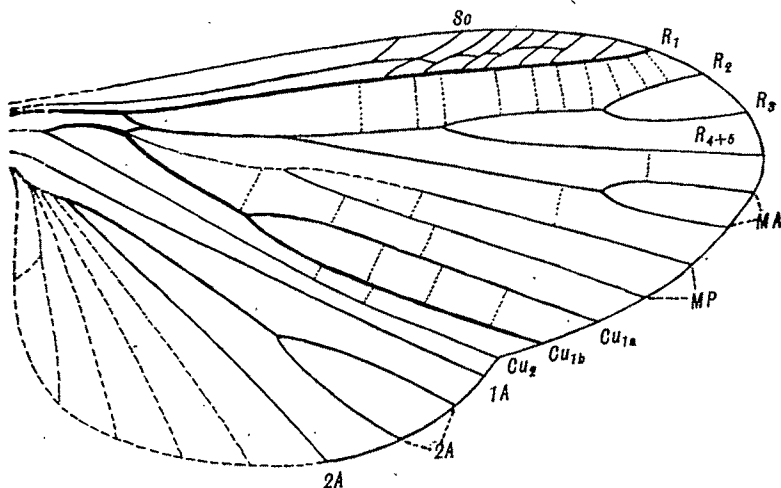


Fig. 7. *Artinska clara* Sell. Specimen No. 5310. Hindwing, length 9.7 mm. Note fusion of R₃ with MA basally.

supplied with veinlets, not pigmented. Rs arising at about one-third from base, either entirely free from MA (*Artinska*-type), or else fused with it not far from origin for a distance ranging from a mere point up to about 1 mm. (*Estadia*-type); usually two-branched, more rarely three-branched. MA normally two-branched, more rarely simple or three-branched, arising from MP usually well before the level of origin of Rs, rarely at about that level. MP normally two-branched, more rarely simple or three-branched, a portion of its basal stalk obsolescent. Cu₁ a very strongly formed, convex vein, normally with three very characteristically formed branches Cu_{1a}, Cu_{1b} and Cu_{1c}, of which the first two arise from a common stalk

placed anterior to the last. Cu_2 straight, very weakly chitinized, ending at about two-fifths along the posterior margin. Anal veins two, simple or branched, very variable, connected together by several stout, longitudinally placed cross-veins. Cross-veins present in all parts of the wing, very irregularly placed; costal veinlets forming a more or less complete series but very weak or obsolescent basally. A marked color-pattern of very dark pigment present, consisting of the elongated patch along R_1 basally, already mentioned, a large irregular patch covering Cu_1 at about one-third from base, another large irregular patch covering Rs and MA at about one-half, and a third covering the area from Rs to MP below the pterostigma; this latter rarely extends to the apex of the wing. *Chaetotaxy*.—Both upper and under surfaces are covered with an immense number of minute, very short microtrichia, while vein Sc carries on its underside a row of stiff macrotrichial bristles.

Hindwing (Fig. 7).—Length 9.7 mm., very broad, with marked re-entrant angle at end of Cu_2 ; costal veinlets absent or obsolescent; pterostigmatic veinlets present and well formed, connected with cross-veins which appear to extend to the distal end of the very slightly curved Sc . R nearly straight, strong, ending well before apex. Rs arising not far from base and fusing for a considerable distance with MA , which arises just below it; more rarely, both MA and MP may be fused with Rs , the latter for a short distance, and, still more rarely, Cu_1 , after arching up from its origin, may also fuse with it at a point; Rs two- or three-branched. Cu_1 strongly arched basally and more or less fused with MA ; Cu_1 two-branched, the fork being very deep and arising at about two-fifths of the length of the vein. Cu_2 and $1A$ simple, straight, close together distally. $2A$ with apparently six main branches, of which the most anterior is distally forked. Cross-veins few, irregularly placed, very faint.

Types:—*Holotype forewing*, Specimen No. 115 in Sellards' Collection. *Paratypes* from the Yale University Collection:

Forewings, Artinska-form:—Specimens No. 1003 *a-b*, 5263 *a-b*, 5265, 5286 *a-b*, 5287 *a-b*, 5289 *a-b*, 5290 *a-b*, 5292 *a-b*, 5293 *a-b*, 5294, 5332 *a-b*, 5333 *a-b*, 5334 *a-b*, 5335 *a-b*, 5336 *a-b*, 5337 *a-b*, 5338 *a-b*, 5339 *a-b*, 5340 *a-b*, 5341 *a-b*, 5342 *a-b*, 5343 *a-b*, 5344, 5345, 5346, 5347, 5348, 5349. No. 5289 *a-b* is var. *submaculata*, with the cubital blotch absent, the median blotch very small, the distal blotch diffuse and two other small blotches in distal part of wing.

Forewings, Estadia-form:—Specimens No. 5264 *a-b*, 5295, 5296 *a-b*, 5297 *a-b*, 5298 *a-b*, 5299 *a-b*, 5301 *a-b*, 5302, 5303, 5304, 5305, 5351 *a-b*, 5352 *a-b*, 5353 *a-b*, 5354 *a-b*, 5355 *a-b*, 5356.

Forewings, Lectrum-form:—Specimens No. 5300 *a-b*, 5306.

Hindwings:—Specimens No. 5307, 5308 *a-b*, 5309, 5310, 5311, 5312, 5357 *a-b*, 5358, 5359, 5360, 5361, 5362, 5363.

Specimens with body more or less complete, wings incomplete:—Specimens No. 5285 *a-b*, 5288 *a-b*, 5350 *a-b*.

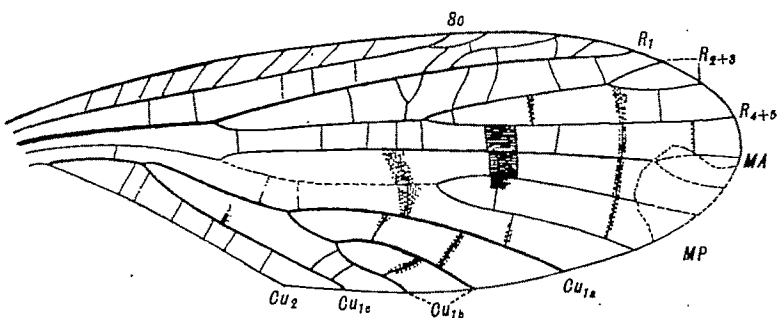


Fig. 8. *Artinska sellardsi*, n. sp. Specimen No. 5291. Forewing, length 10.5 mm.

All the above are in Yale University except Nos. 5263 *a-b*, 5289 *a-b*, 5295, 5297 *a-b*, 5304, 5305, 5312, 5345, 5363 and the counterparts (marked "b") of Nos. 5285, 5290, 5291, 5296, 5300, 5301, 5308, 5332, 5337, 5339, 5341, 5350, 5353, 5359, which are in the Cawthron Institute.

Total number of specimens:—Sixty-four, of which no fewer than thirty-nine have counterparts.

Artinska sellardsi, n. sp.

(Fig. 8.)

This new species is founded on a single forewing, well preserved except for the loss of the entire anal area. *Length* 10.5 mm., *greatest breadth* 3.6 mm.; *ratio of length to breadth* 2.9:1. It differs from *A. clara* Sell. in the following important points:—General structure of the veins less robust. Sc a straight vein running quite to two-thirds along costa, and having its distal end connected only with the first pterostigmatic veinlet; second pterostigmatic veinlet very elongated with cross-veins below it; only one more short veinlet from R,

beyond it. R_1 markedly bent at origin of R_s (as in the following species also, but in *A. clara* R_1 is not bent at all at this point). MA arising below level of origin of R_s , simple and almost straight, ending at apex of wing. MP with a curved stalk (straight in *A. clara*) and large terminal fork. Cu_{1a} longer and more arched than in *A. clara*; Cu_{1b} with an extra fork of considerable size (this might be purely an individual character). Cross-veins fewer than in *A. clara*. Chaetotaxy very faint, the microtrichia excessively minute and delicate. Color-pattern consisting of a subrectangular blotch of smoky

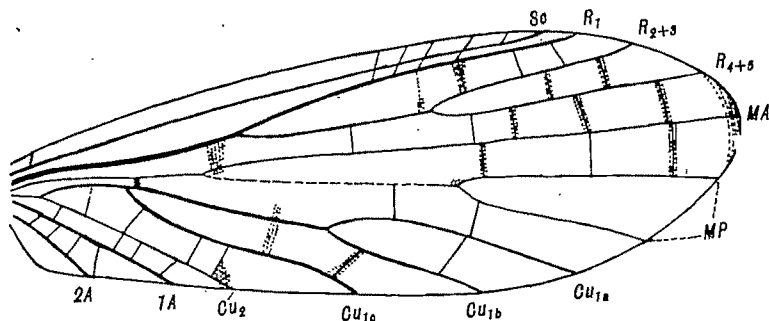


Fig. 9. *Artinska ovata* (Sell.). Specimen No. 5315. Forewing, length 6.6 mm. Normal *Artinska*-form, with M and Cu_1 separate.

pigment at about two-thirds from base, passing from lower branch of R_s to just beyond upper branch of MP, and slight infuscation along the courses of a few cross-veins in distal half of wing.

Types.—*Holotype forewing*, Specimen No. 5291 *a* in Yale University Collection and counterpart No. 5291 *b* in Cawthron Institute Collection.

Artinska ovata (Sell.).

(Figs. 9-12.)

Orta ovata Sellards, 1909, p. 168 and p. 164, Fig. 23.

This fairly common species is represented by about thirty specimens in the Yale University Collection, with eleven counterparts. There is never any tendency for MA to approach or fuse with R_s ; but, on the other hand, all stages of approach of the arched basal piece of Cu_1 towards M can be found, and in eleven out of the thirty specimens fusion has actually taken place between these two veins. Occasionally (Fig. 11) the fusion is so complete that it practically reaches

the type shown in *Lecorium* and *Stemma* (Figs. 16-18). According to Sellards, this character differentiates the family Ortidae from the family Lemmatophoridae. But a study of a long series of forms shows that not only are the two families the same, but also the two genera *Orta* and *Artinska* (for the

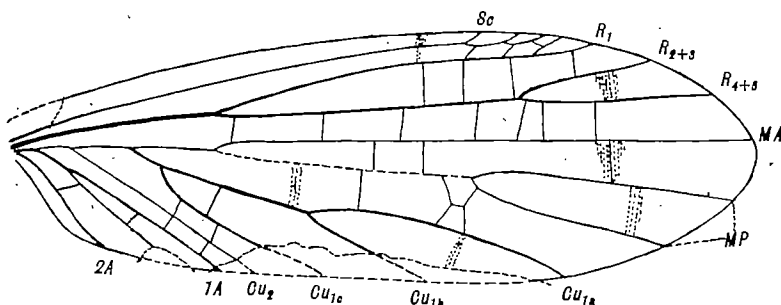


Fig. 10. *Artinska ovata* (Sell.). Specimen No. 5323. Forewing, length 6.6 mm. *Orta*-form, with M and Cu₁ fused basally.

other nineteen specimens fall into this genus, not one of them being of the *Estadia* or *Lectrum* type), and that the species *Orta ovata* Sell. should therefore be removed to the genus *Artinska* Sell., which has priority over *Orta* Sell.

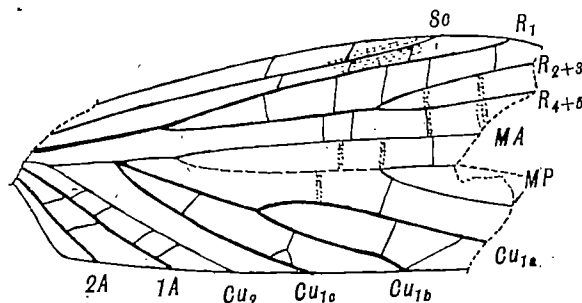


Fig. 11. *Artinska ovata* (Sell.). Specimen No. 5322. Forewing, incomplete. *Orta*-form, with fusion between M and Cu₁ almost at *Lecorium*-stage.

Forewing.—Total length 6.5 to 7.5 mm.; greatest breadth 2.3 mm. to 2.7 mm.; ratio of length to breadth 2.8—2.9:1.

This species is well defined by the long and very slightly curved Sc, which reaches close up to the end of R₁, making the pterostigmatic region short; the distal end of Sc is some-

times ill-defined and sometimes appears to run through a number of veinlets, but is not easy to make out. The costal series of veinlets is either entirely missing or only faintly visible (only seen in one or two of the most darkly marked wings). R_1 is markedly bent at origin of Rs; the stalk of the latter is nearly straight, with large to medium terminal fork. M is always well separated from R basally, but either close to or actually fused with Cu_1 . MA is a simple vein running straight through the middle of the wing to the rounded apex. MP has a straight, obsolescent stalk and large, wide terminal fork. Cu_1 has the normal, three-branched form typical of the

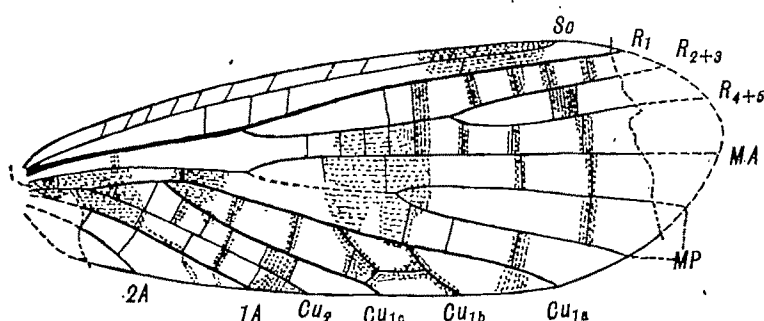


Fig. 12. *Artinska ovata* (Sell.). Specimen No. 5317. Forewing, incomplete. Var. *colorata*. (Venation of normal *Artinska*-form, with M and Cu_1 separate.)

genus. Cu_2 is shorter than in the other species, ending at little beyond one-fourth from base. Anal veins simple or, more rarely, 1A forked; anal angle obtuse. Chaetotaxy very faint. Color-pattern of irregular patches of smoky or brownish pigment of light to medium intensity, very variable, but consisting essentially of a basis of pigmentation around a number of variably placed cross-veins; in the lightest forms (Figs. 9, 10) this is all, but in more heavily marked forms (var. *colorata*, Fig. 12) the pigment tends to broaden out into transverse patches, and occasionally two or more patches may fuse to form a larger blotch. No two specimens show the same color-scheme, but this is scarcely surprising when we remember that the cross-veins vary from specimen to specimen, and that the color-pattern is formed basically around them. In one or two specimens the pterostigma, in others the whole of the anal area right across to Cu_{1c} , is infusate. Cu_1 has an

extra branch in Specimen No. 5330, and is irregularly formed in No. 5317 (Fig. 12).

Types:—*Holotype forewing* Specimen No. 295 in Sellards' Collection. Paratype forewings from Yale University Collection:

(*Artinska*-type) Specimens No. 5313 *a-b*, 5314 *a-b*, 5315 *a-b*, 5316 *a-b*, 5317 *a-b*, 5318, 5319, 5320, 5321, 5364 *a-b*, 5365 *a-b*, 5366, 5367, 5370 *a-b*, 5371, 5372, 5373, 5374, 5375.

(*Orta*-type) Specimens No. 5322 *a-b*, 5323 *a-b*, 5324 *a-b*, 5325, 5326, 5327, 5328, 5329, 5330, 5331, 5369. Doubtful, No. 5368.

All the above are in Yale University except Nos. 5372, 5374, 5325, 5327, 5329 and the counterparts (marked "b") of Nos. 5313-7, 5365, 5323-4, which are in the Cawthron Institute.

There are no hindwings which I can place with any certainty in this species.

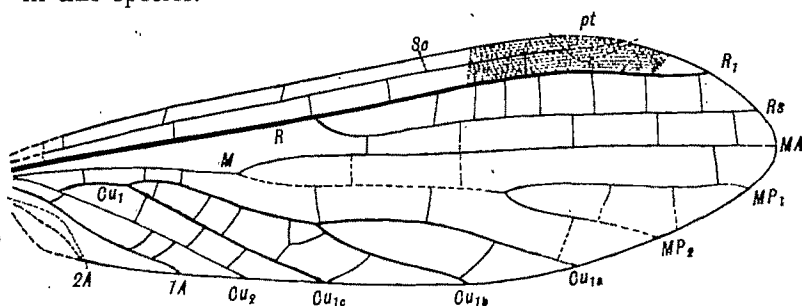


Fig. 13. *Paraprisca fragilis* (Sell.). Specimen No. 5194. Forewing, length 10.5 mm. Form with Rs and MA separate.

Genus *Paraprisca* Handl.

(Figs. 13-15.)

Prisca Sellards, 1909, p. 167 (nec *Prisca* K. v. Fritsch, 1899).

This genus is closely allied to *Lemmatophora* Sell., from which it differs only in the more elongate form of forewing with less rounded apex, and in its having a much greater tendency to the fusion of Rs with MA for a short distance near the origin of the former vein. Sc is straight, long, and close to the costal margin; the costal veinlets few and weak. Rs is simple and arises between one-third and half-way from the base. MA simple, arched basally and then running straight to apex of wing; it may be either well separated from Rs (Fig. 13), close to it (Fig. 14, C), or fused with it for a less or

greater distance (Fig. 14, B, A). MP forked, with obsolescent stem. Cu_1 normally three-branched. Cu_2 straight, simple, weakly formed, ending at about one-fourth along the posterior margin. Anal veins simple, the anal area rather narrowed, with obtuse anal angle. *Hindwing* as in *Lemmatophora*, but Sc longer and straighter, parallel to and about equidistant between costa and R_1 . Rs strongly fused basally with MA to beyond one-third. MP strongly forked (simple in *Lemmatophora*). MA simple. Cu_1 with a very large fork. Apparently no re-entrant angle at end of Cu_2 , but contour of wing continuous along the outer margin past this vein; conse-

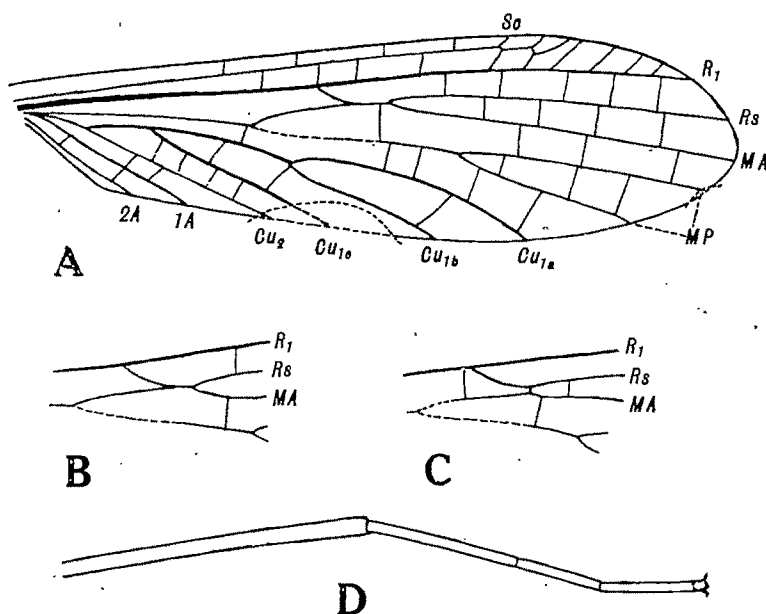


Fig. 14. *Paraprisca fragilis* (Sell.). A, Specimen No. 5250, forewing, length 9.0 mm., with Rs and MA well fused. B, Specimen No. 5253, detail of forewing, showing slight fusion between Rs and MA. C, Specimen No. 5255, detail of forewing, showing Rs and MA almost touching. D, Specimen No. 5251, tibia and tarsus of hind leg.

quently, the general form of hindwing is longer and less broadened than in *Lemmatophora*. Cross-veins in both wings only moderately numerous. General build of insect slender, with long, slender legs.

Genotype.—*Paraprisca fragilis* (Sell.).

Horizon.—Lower Permian of Kansas.

Eleven specimens of this genus are present in the Yale University Collection, with six counterparts. I consider these all to belong to a single species, *Paraprisca fragilis* (Sell.), which shows considerable variation in the venation.

Paraprisca fragilis (Sell.).

(Figs. 13-15.)

Head small. *Thorax* rather slender, the prothorax rather small, with semicircular lateral expansions of less size, comparatively, than in *Lemmatophora typica* Sell. *Legs* (Fig. 14, D) very long and slender. (Antennae and cerci not preserved in any known specimen.)

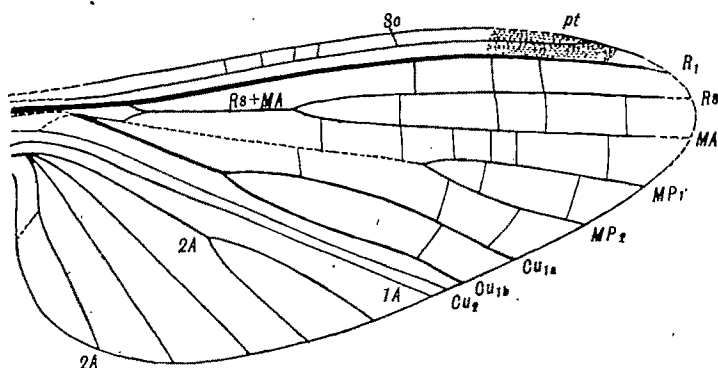


Fig. 15. *Paraprisca fragilis* (Sell.). Specimen No. 5262. Hindwing, length 9.4 mm.

Forewing:—Length 9.0 to 10.5 mm.; greatest breadth 2.5 to 3.2 mm.; ratio of length to breadth 3.3—3.6:1. Coloration hyaline, with dark venation but no pigmentation except, sometimes, a slight shading on the pterostigma; cross-veins slender, not surrounded by pigmentation areas. Costal margin almost straight to pterostigma. Sc long and straight, ending well into the pterostigma; in the latter, weak veinlets may or may not be visible. R₁ not bent at origin of Rs. Rs considerably curved at origin, then running fairly straight to a little above apex. The variations in the freedom or fusion of Rs and MA are well shown in Figs. 13, 14. M arising well below R and diverging markedly from it; origin of MA at about one-third; fork of MP at about half-way along that vein. Anterior fork of Cu₁ large, with Cu_{1a} appreciably arched and reaching to

two-thirds or more along posterior margin. 1A and 2A straight or slightly waved; anal angle always obtuse, but of variable prominence.

Hindwing slightly shorter than fore, with Rs arising much closer to base and fusing almost immediately with MA for a considerable distance. M and Cu₁ in close contact with R near base. Pterostigma faintly pigmented.

Legs (Fig. 14, D) long and slender, with very slender tibia and tarsus; no spur on tibia; tarsus with the three segments in the ratio of 12:7:8, the claws very small.

Types:—*Holotype forewing* No. 128 in Sellards' Collection. *Paratypes* from Yale University Collection.

More or less complete specimens:—Nos. 5194 *a-b* (forewing with Rs and MA free), 5251 (forewing with Rs and MA fused), 5252 *a-b* (forewing with Rs and MA fused on left, just touching on right), 5284 (complete body, with antennae, legs and cerci broken off, forewing and part of hind), 5262 *a-b* (part of thorax with hindwing).

Forewings with Rs and MA separate:—No. 5257 *a-b* (nearly touching, joined by a very short cross-vein).

Forewings with Rs and MA fused:—Nos. 5250 (long fusion), 5253 *a-b* (short fusion), 5254 (short fusion), 5255 *a-b* (touching at a point), 5256 (long fusion), 5258 *a-b* (short fusion).

Hindwing only:—No. 5195.

All the above are in Yale University except the counterparts (marked "b") of Nos. 5194, 5252, 5255, 5257, 5258 and 5262, which are in the Cawthron Institute.

Group *Prosaites-Lecorium-Stemma*.

We now have to consider a very difficult group of forms, which may be called the *Prosaites-Lecorium-Stemma* group for convenience. Of these three generic names, *Prosaites* Sell. (l. c., p. 167) takes priority over *Lecorium* Sell. (l. c., p. 167) and *Stemma* Sell. (l. c., p. 168). *Prosaites*, however, is not figured, and the definition of the genus and descriptions of the two alleged species are totally inadequate for recognition. No separate definition of the genus is attempted, and all we have to go upon are the following two brief specific diagnoses:

"Prosaites compactus gen. et sp. n.

"The front wings of species of this genus are compact, the cross veins numerous. The radial sector is bifurcate. M₁ is simple;

M_2 is branched. Cu_1 and Cu_2 are both simple. The sector in the type species is united with media for a short distance only. Length of front wing, $8\frac{1}{2}$ mm.; width, 3 mm. Type, No. 628."

"*Prosaites secundus* sp. n.

"The radial sector of this species is united with M_1 for a distance of about one millimeter. M_2 is deeply forked. Length of front wing, $8\frac{1}{2}$ mm.; width, 3 mm. Type, No. 241."

What Sellards means by the forewings being "compact" is not clear, but the measurements given for both "species" yield a ratio of length to breadth equal to 2.8, or well below 3.0. This puts *Prosaites* Sell. into the broad-winged group typified by *Lemmatophora* and *Artinska*. On the other hand, the only specimens that I can find in the whole of the Yale University Collection, characterized by a two-branched Cu_1 (which is what Sellards means when he says " Cu_1 and Cu_2 are both simple," since his Cu_2 is my Cu_{1c}), have a ratio of about 3.3, and are quite clearly of the elongate-winged group typified by *Paraprisca* Handl. The types of *Prosaites* are apparently lost, and so this problem must remain insoluble. In view of the fact that both *Lecorium* Sell. and *Stemma* Sell. are figured on p. 164 of his work, i.e., three pages before the inadequate description of *Prosaites*, I think it will be allowable for us to sink the latter name, at any rate until such time as the discovery of the types and a further study of them may reopen the question.

Now, turning to the group of forewings in the Yale University Collection which possess this remarkable character of a two-branched abnormal Cu_1 , we find five such specimens, viz., Nos. 5267, 5278, 5279, 5280, 5281. In every one of these, it is also to be noted that MP is three-branched instead of two-branched (the normal condition). Further, the extra (most posterior) branch of MP is seen to be a thickened, convex vein resembling the branches of Cu_1 , whereas the other two branches are very delicate and concave. The conclusion is inevitable that these five specimens have the normal three-branched condition of Cu_1 , but that Cu_{1a} has become switched over to MP.

If that is so, we ought to find connecting links between this form and the normal form with Cu_1 three-branched. Such are Sellards' type No. 31 of *Stemma elegans* (l. c., p. 164, Fig. 27)—which is obviously the same thing as his *Lecorium elongatum* (l. c., Fig. 26) but has Cu_{1a} switched over to MP while developing a small apical fork on Cu_{1b} —and No. 5269, in which Cu_1 has four branches, but the most anterior of these is

almost as much connected with MP as with Cu_1 . Along another line, No. 5280 is also an intermediate type, suggesting that the switching took place by enlargement of Cu_1^a backwards towards the base until it fused basally with MP. It seems quite clear that, by whatever means it took place, the presence of the extra branch on MP is merely due to removal of Cu_1^a from its original position and its subsequent attachment to MP. Moreover, this same switching is to be found in another set of forewings in the Yale University Collection (Nos. 5267, 5272, 5279, 5281) which have Rs simple. The first of these, No. 5267, will classify as *Stemima* in every particular (even down to the extra small apical fork on Cu_1^b) except that it has Rs and MA fused instead of separate. The other three lack the small apical fork on Cu_1^b .

There is only one conclusion to come to from all this, viz., that the abnormal switching of Cu_1^a over to MP is purely an individual character, just as the freedom or fusion of Rs with MA is. In fact, in all these wings, there seems to be only one constant venational character, viz., that MA is always simple. When we look about for characters on which to base our genera, we find that we must fall back on the same one used in dividing up the broad winged forms, viz., the simple or branched condition of Rs. In doing this, no notice must be taken of small apical forks, such as are to be found on Rs in Sellards' type of *Lecorium elongatum* (l. c., Fig. 26). This will give us two fairly reliable genera, one of which must take the name *Lecorium* Sell. (Rs simple or with tiny apical fork), and the other requires a new name. For this I propose here the name *Sellardsia*, n. gen., in honor of the discoverer of the Kansas Lower Permian fossil insect beds. We can then classify the known elongate-winged forms of the family Lemmatophoridae by the following key:

1. No fusion basally between M and Cu_1 Genus *Paraprisca* Handl.
M and Cu_1 fused basally. 2.
2. Rs simple or at most with a tiny apical fork. Genus *Lecorium* Sell.
Rs strongly forked, with or without an extra small apical fork.
Genus *Sellardsia*, n. gen.
(Genotype: *S. kansasensis*, n. sp.)

Before proceeding to the definition of the two genera *Lecorium* and *Sellardsia*, it would be as well to summarize the results of our analysis of the available specimens in the form of a table. This table arranges the Yale Collection specimens tentatively under the Sellardsian genera as far as possible, including *Prosaites* for those which have Rs forked and Cu_1

only two-branched, irrespective of ratio of length to breadth. Those which will not go into any Sellardsian genus are called, in the table, "new variety." I think it will readily be apparent from the analysis that *Stemma* Sell. = *Lecorium* Sell., that the "new varieties" with Rs simple will fall into *Lecorium* Sell., and that all forms (including the "*Prosaites*" ones in the table) having Rs forked will come under the new genus *Sellardsia*:

Table of Ratios and Venational Variations for the Group
Prosaites-Lecorium-Stemma.¹

No.	Group	Length	Breadth	Ratio	Fusion of Rs with		Number of branches of		
					MA	Rs	MA	MP	Cu ₁
S. 524	<i>Lecorium</i>	8 mm.	2¾ mm.	2.9	Nil.	1½	1	2, normal	3, normal
			(ratio in fig. = 3.3)						
5270	"	7.5	2.4	3.2	Slight.	1	1	2, normal	3, normal
5273	"		(Incomplete)		Nil.	1	1	2, normal	3, normal
5274	"	8.2	2.4	3.4	Nil.	1	1	2, normal	4, abnormal
5275	"		(Incomplete)		Long.	1	1	3, abnormal	3, normal
5276	"		(Incomplete)		Long.	1	1	2, normal	3, normal
S. 31	<i>Stemma</i>	10	2½	4.0	Nil.	1	1	2 + Cu _{1a}	2½, abnorm
			(ratio in fig. = 3.3)						
S. 1272	"	8	2½	3.2	Nil.	1	1	2 + Cu _{1a}	2½, abnorm
5272	"		(Incomplete)		Long.	1	1	2 + Cu _{1a}	2½, abnorm
5267	New variety	7.0	2.1	3.4	Slight.	1	1	2 + Cu _{1a}	2, abnormal
5279	"		(Incomplete)		Nil.	1	1	2 + Cu _{1a}	2, abnormal
5281	"		(Incomplete)		Slight.	1	1	2 + Cu _{1a}	2, abnormal
S. 628	<i>Prosaites</i>	8½	3	2.8	Slight.	2	1	2 + ?	2, abnormal
S. 241	"	8½	3	2.8	Long.	2	1	2 + ?	2, abnormal
5278	"	9.1	2.5	3.6	Long.	2½	1	2 + Cu _{1a}	2, abnormal
5280	"		(Incomplete)		Slight.	2	1	2 + Cu _{1a}	2, abnormal
5266	New variety	8.6	2.5	3.4	Long.	2	1	3, abnormal	3, normal
5268	"	8.4	2.4	3.5	Long.	2½	1	1, abnormal	3-MP ₂
5269	"	8.6	2.5	3.4	Nil.	2	1	2, normal	4, abnormal
5271	"	6.4	1.9	3.4	Long.	2	1	2, normal	3, normal
5277	"		(Incomplete)		Nil.	2	1	1, abnormal	3, normal

¹ In the above table, Sellards' types have their numbers prefixed by the letter "S." Specimens having Cu_{1a} attached to MP are classified as belonging to the *Prosaites*-group if they have a forked Rs, irrespective of ratio of length to breadth; but if they have a simple Rs, then they are classified as "new variety."

Genus *Lecorium* Sell.

(Figs. 16-18.)

Lecorium Sellards, 1909, p. 167, and p. 164, Fig. 26.

Stemma Sellards, 1909, p. 168, and p. 164, Fig. 27.

A genus of moderate-sized insects in which the forewing is of the more elongate type, with ratio of length to breadth greater than 3.0. It agrees with *Paraprisca* Handl. in having

R_s simple, or at most with only a tiny apical fork, in the simple MA, and in the strong tendency of R_s and MA to fuse together for a space, but differs from that genus in the more rounded apex, the broader basal portion, the nearly parallel direction of costa and posterior margin, and the strong fusion of Cu_1 with M near base. Another striking character in which this and the succeeding genus stand out from *Paraprisca* is the great strength of R_1 and 1A; in connection with the latter, one must note the great contrast between the strong, dark, convex 1A and the almost obsolete Cu_2 , and, in well-preserved forewings, one should note that the cross-veins passing from 1A to Cu_2

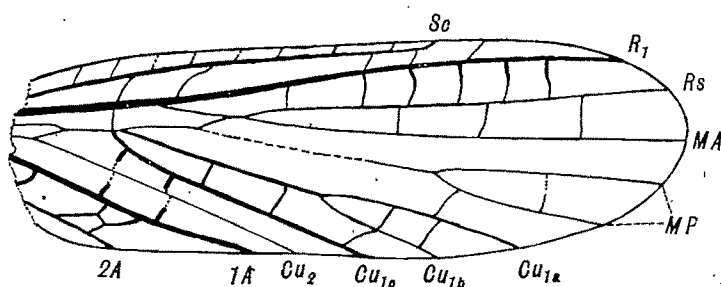


Fig. 16. *Lecorium elongatum* Sell. Specimen No. 5270. Forewing, length 7.5 mm. *Lecorium*-form, but without small apical fork to R_s .

are stout and dark, like 1A, for that portion of their length which abuts on that vein, while they become obsolescent as they approach Cu_2 . The effect produced by the contrast of these two veins and their cross-veins is, in a well-preserved specimen, so marked as to catch the eye at once. The hindwing of this genus is not known.

Genotype.—*Lecorium elongatum* Sell.

Horizon.—Lower Permian of Kansas.

Lecorium elongatum Sell.

(Figs. 16-18.)

Lecorium elongatum Sellards, 1909, p. 167, and p. 164, Fig. 26.

Stemma elegans Sellards, 1909, p. 168, and p. 164, Fig. 27.

Stemma extensa Sellards, 1909, p. 168.

Forewing.—Length 7.0 to 8.2 mm.; greatest breadth 2.1 to 2.4 mm.; ratio of length to breadth 3.2–3.4:1. Membrane hyaline, but veins very dark, also many of the cross-veins. Sc running close to costa, with irregular, short costal veinlets

present, but often obsolescent; pterostigmatic area with only two or three veinlets; distal portion of Sc connected with R_1 by cross-veins. R_1 straight, ending well before apex. Rs and MA simple, either free or fused basally not far from origins to a greater or less extent. MP normally two-branched, rarely

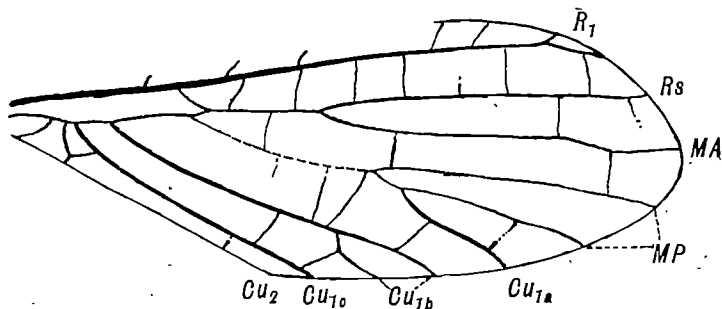


Fig. 17. *Lecorium elongatum* Sell. Specimen No. 5272. Forewing, incomplete. Stemma-form, exact, with extra branch of Cu_{1a} and with Cu_{1b} attached to MP.

with an extra branch, often with Cu_1 attached to it posteriorly. Cu_1 normally three-branched, sometimes with an extra small fork on Cu_{1b} . Cu_2 straight; obsolescent, ending somewhat beyond one-third along posterior margin. $1A$ long, straight

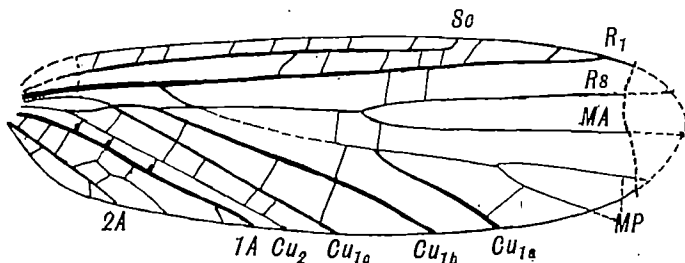


Fig. 18. *Lecorium elongatum* Sell. Specimen No. 5267. Forewing, length 7.0 mm. Stemma-form, but with Cu_{1b} normal.

or nearly so, close to Cu_2 , very stout and dark, simple; rarely abnormal, with one or two thick, dark, closed loops along its course. $2A$ well separated from $1A$, slenderer, diverging, simple or branched; some strong cross-veins in the anal area. Anal angle obtuse or moderately rounded.

Types.—*Holotype forewing* in Sellards' Collection, No. 524, *paratypes* (*Stemma*-form) in same collection, Nos. 31 and 1272. From the Yale University Collection the following *paratype forewings* may be classified under their varieties:

Normal *Lecorium*-form (Fig. 16), but without any small apical fork to Rs:—Specimens No. 5270, 5273, 5274 *a-b*, 5275, 5276 *a-b*, 5277 *a-b*.

Stemma-form exact (Fig. 17) with extra fork on Cu_{1b} and with Cu_{1a} switched over to MP:—Specimen No. 5272.

Stemma-form, but with Cu_{1b} normal (Fig. 18):—Specimens No. 5267, 5279 *a-b*, 5281 *a-b*.

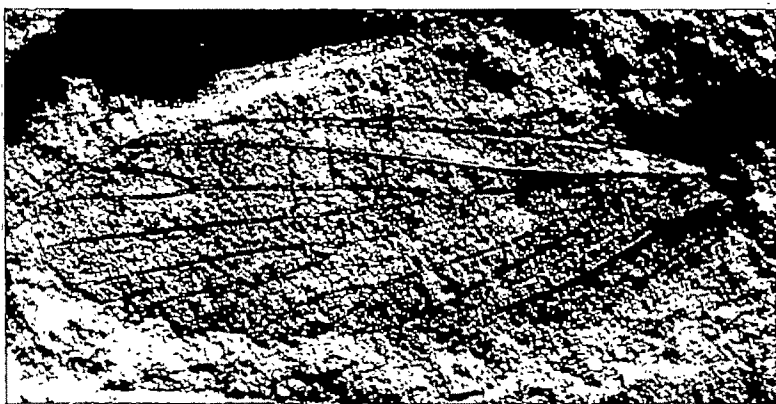


Fig. 19. *Sellardsia kansasensis*, n. gen. et sp. Specimen No. 5266. Forewing, length 8.6 mm. *Sellardsia*-form, with normal three-branched Cu_1 . Photo. by W. C. Davies.

All the above in Yale University except No. 5273 and the counterparts (marked "b") of Nos. 5274, 5276, 5277, 5279 and 5281, which are in the Cawthron Institute.

Genus *Sellardsia*, n. gen.

(Figs. 19-22.)

This genus is very closely allied to *Lecorium* Sell., from which it differs only in having Rs strongly forked instead of simple; an extra small apical fork may also be present on R_{2+3} .

Genotype.—*Sellardsia kansasensis*, n. sp.

Horizon.—Lower Permian of Kansas.

There are two species, separated as follows:

- Larger species, with forewing 8–9.5 mm. long and apex slightly pointed.
S. kansasensis, n. sp.
 Smaller species, with forewing 6–7 mm. long and apex more rounded.
S. lecorioides, n. sp.

Sellardsia kansasensis, n. sp.

(Figs. 19–21.)

Forewing:—Length 8.4 to 9.1 mm.; greatest breadth 2.4 to 2.5 mm.; ratio of length to breadth 3.4–3.6:1. Sc arising close to R but running close to costa for most of its length and

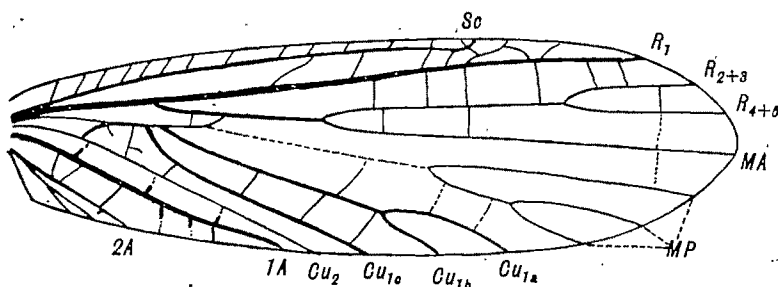


Fig. 20. *Sellardsia kansasensis*, n. gen. et sp. Specimen No. 5266. Forewing, length 8.6 mm. *Sellardsia*-form, with normal three-branched Cu_1 .

ending at two-thirds or beyond. Costal and pterostigmatic veinlets present, irregularly placed, also cross-veins between R_1 and distal end of Sc. R_1 straight, very strong, ending well before apex. Rs arising at or before one-fourth, either free or more or less fused with MA. Forking of Rs variable but always considerable. MA simple, running to apex, which is slightly but distinctly pointed. MP normally two-branched, rarely three-branched, and sometimes with Cu_{1a} attached to it (Fig. 21). Cu_1 with its two main branches arising separately from M and diverging very slightly distally; a series of strong cross-veins between them. Cu_2 obsolescent, ending between one-third and one-half along posterior margin. 1A long, converging distally to Cu_2 . 2A much shorter, simple or narrowly branched, much slenderer than 1A. Anal angle obtuse. *Coloration* hyaline in most specimens, the pterostigma sometimes shaded; but Specimen No. 5269 is pigmented all over.

Hindwing:—Specimen No. 5282 is a hindwing, with anal fan missing, which almost certainly belongs to this species.

Length 8.2 mm.; breadth at end of Cu_2 2.9 mm. Costa and Sc slightly concave to pterostigma, which is lightly pigmented; rest of wing hyaline. R_1 waved, ending somewhat before apex of wing, which is rounded. Rs arising close to base, three-branched (including small terminal fork) and fused basally for a short distance with the very weakly formed M; the latter vein forks beyond half-way into a simple MA and deeply forked MP. Cu_1 with a strong, straight main stem,

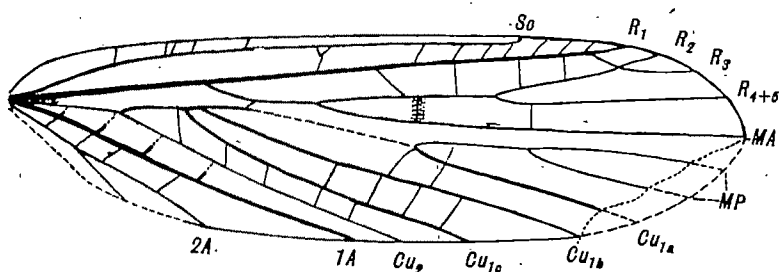


Fig. 21. *Sellardsia kansasensis*, n. gen. et sp. Specimen No. 5278. Forewing, length 9.1 mm. *Prosaetes*-form, with Cu_1 apparently only two-branched owing to attachment of Cu_{1a} on to MP.

Cu_{1c} , from which arise two arched branched Cu_{1a} and Cu_{1b} ; the former of these touches M at about middle of wing. Cu_2 weak, parallel to Cu_{1c} . 1A a long, strongly formed vein, close to and parallel to Cu_2 . Rest of anal area, including the whole of the anal margin, missing.

Types:—*Holotype* forewing, Specimen No. 5266 a in Yale University Collection, with holotype-counterpart No. 5266 b in Cawthron Institute Collection. *Paratypes*:—*Forewings*, Nos. 5269, 5278 (Fig. 21) and 5280 in Yale University Collection, 5268 in Cawthron Institute Collection; *hindwing* No. 5282 in Yale University Collection. Specimen No. 5283 in Yale University Collection, showing portion of body, both forewings and one hindwing, but with venation not very clear, also appears to belong to this species.

Sellardsia lecorioides, n. sp.

(Fig. 22.)

This species is based on a single complete forewing, measuring only 6.4 mm. in length by 1.9 mm. in breadth; ratio of length to breadth, 3.4:1. It differs from the previous species in

having the apex more rounded, the origins of Rs and the branches of Cu_1 further apart, and 1A not quite so close to Cu_2 . It bears a close resemblance to the forewing of *Lecorium elongatum* Sell. (Fig. 16), from which it can be separated by the shorter R_1 , the more distal origin of Rs, and the forked condition of that vein.

Type.—*Holotype forewing*, Specimen No. 5271 a in Yale University Collection, with holotype-counterpart No. 5271 b in Cawthron Institute Collection.

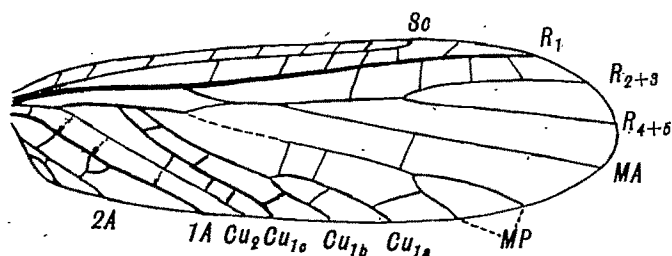


Fig. 22. *Sellardsia lecorioides*, n. sp. Specimen No. 5271. Forewing, length 6.4 mm. Normal form.

SUMMARY OF THE ORDER PROTOPERLARIA AND THE FAMILY LEMMATOPHORIDAE.

In concluding this account of the order Protoperlaria and family Lemmatophoridae, I wish to emphasize the simplicity of the definition of the order, as indicated in my original account in *Nature* (1926). The sole criteria for this order are the presence of the lateral, wing-like expansions of the pronotum and the general Perlarian facies, venation and chaetotaxy of the wings. The order differs from the Perlaria in the presence of the pronotal expansions, which are much reduced in true Perlaria and no longer show anything of a wing-like appearance, and in the presence, in both wings, of the concave vein MP (homologue of the concave M of most insects), which is already becoming obsolete basally, but which, in the true Perlaria, has entirely disappeared; it agrees with true Perlaria in the general chaetotaxy (but the microtrichia are shorter and stiffer), in the general facies, the morphology of the head, antennae, abdomen and cerci, the absence of an appendix dorsalis, and in the general shape of the wings, the presence of a large anal fan in the hindwing, and especially in the partial fusion, in that wing, of Rs and MA.

In comparing true *Perlaria* with *Protoperlaria*, I am impressed with the family *Austroperlidae* as showing the closest existing types to these fossil forms. If one were to ask, which genera of the *Protoperlaria* gave rise to the *Austroperlidae* and the other existing families of true *Perlaria*, it would seem fairly obvious that we must eliminate those genera having specialized vein-fusions not found in recent forms, and this would leave us with only *Lemmatophora*, *Artinska* and *Paraprisca* as the possible ancestors. As modern *Perlaria* have MA universally two-branched and Rs is for the most part also branched, we may, I think, with considerable certainty, indicate *Artinska* as the actual ancestor of the existing order.

In concluding this paper, I append a table showing the relationships of the genera of the family *Lemmatophoridae*:

Table of Relationships of the Genera in the Family
Lemmatophoridae.

Characters of Venation		Broader-winged forms (ratio of length to breadth less than 3.0)	Narrower-winged forms (ratio 3.2 or over)
Rs simple	M & Cu free	<i>Lemmatophora</i> Sell.	<i>Paraprisca</i> Handl.
Rs simple	M & Cu fused	.....	<i>Lecorium</i> Sell.
Rs forked	M & Cu free	<i>Artinska</i> Sell. (normal type)	.....
		↓	
Rs forked	M & Cu fused	<i>Artinska</i> Sell. (Orta-type)	<i>Sellardsia</i> , n. gen.

Note on the New Order *Miomoptera* Martynov.

Martynov has published (1927) a paper in which he defines this new order and includes in it the families *Palaeomantidae*, *Delopteridae*, *Lecoriidae*, *Lemmatophoridae*, *Probnisidae* and *Liomopteridae*. The ordinal characters relied upon for such a diverse assemblage of forms appear to be of no real value whatever. For example, the size of the insect ("kleine Insekten, deren Vorderflügelänge von 4.5–15 mm. schwankt, etc.") is surely not of ordinal value; the statement that the longitudinal veins are, at least basally, provided with rather strong hairs is by no means generally true, while the definition "Sc der Vorderflügel stark verkürzt" would drive most of the Kansas forms outside the order. The presence of MA and MP is a good ordinal character, but is shared with other orders also. A number of variable venational characters are also

given for the order, but some of these will not even hold water for genera or species.

I conclude that the order Miomoptera is an artificial assemblage with nothing to recommend it, and should not have been attempted without a detailed study of the large number of forms involved from the Lower Permian of Kansas. The total known species and genera involved, exclusive of these, is only five genera and nine species from North Russia, and the number of actual specimens is far too small to allow of any wide view of the range of venational variation, such as is gained by the study of the immense number of specimens discovered in the Kansas beds.

As regards nomenclature, my name *Protoperlaria* (*Nature*, June 12th, 1926) must take priority over Martynov's *Miomoptera* (June, 1927) for any order based wholly or partly on the *Lemmatophoridae*. Dr. Martynov was well aware that I was working on these insects, as we were corresponding, and I am sorry that he has seen fit to try to anticipate my results, on a study of insufficient material, when he knew that I had many hundreds of specimens to examine and that some delay in publishing was unavoidable.

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THE CRYSTAL STRUCTURES OF MONOMETHYL AMMONIUM CHLOROSTANNATE AND CHLOROPLATINATE.

RALPH W. G. WYCKOFF.

Introduction. This determination of structure is the first of a series of studies upon ammonium chlorostannates and chloroplatinates in which one or more of the hydrogen atoms are replaced by hydrocarbon chains of various lengths. The chlorostannates are particularly adapted to such an investigation. They crystallize well even when the substituted groups are large, and crystallographic measurement has shown that the symmetry of many of them is surprisingly high. The scattering powers of the tin and chlorine atoms are such that their positions can usually be established by existing methods. When this cannot easily be done with the chlorostannate alone, it can be accomplished with the aid of such isomorphous salts as the chloroplatinate and bromostannate.

A knowledge of the structures of several members of this series may be expected to furnish an independent determination of the sizes and shapes of the carbon chains that are now being studied in this laboratory in the correspondingly substituted ammonium halides. Likewise the examination of salts of mixed amines provides the next step towards the structures of truly organic crystals. Even more significant for crystal analysis itself are the correlations to be established between these different arrangements and the symmetry and relative sizes of the fixed atomic groups of which they are constituted.

The Structure of $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$. The crystals used in this study were grown from solutions obtained by adding SnCl_4 , SnBr_4 or H_2PtCl_6 to water solutions of $\text{NH}_3\text{CH}_3\text{Cl}$ or $\text{NH}_3\text{CH}_3\text{Br}$. The methyl ammonium halide was made by neutralizing methyl amine (from Eastman) with HCl or HBr . Crystals of the double salts were obtained from slowly cooled solutions. They are pseudo-octahedrons upon which the largest face is sometimes the base and sometimes a rhombohedral face.

Spectral and Laue photographs have been made and analyzed in the usual fashion from $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$, $(\text{NH}_3\text{CH}_3)_2\text{PtCl}_6$ and $(\text{NH}_3\text{CH}_3)_2\text{SnBr}_6$. Accurate spac-

ing measurements for each were obtained from comparison spectrum photographs, using the (100) face of calcite as standard. Since more detailed analysis has been carried out upon the chlorostannate and because it grows better and larger specimens, comparison spectra have been analyzed from two of its faces. On account of the imperfection of their (111) faces, the spacings measured for the bromostannate and the chloroplatinate are not of the highest accuracy. The (111) spacings for the chlorostannate are better, though they are not as consistent and probably not as accurate as the data from the more perfect (110) face. The averaged results from these comparison photographs are listed in Table I.

TABLE I.

Averaged Results of Spacing Measurements from Basal Planes.

Film No.	(111) Spacing for		
	$(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$	$(\text{NH}_4\text{CH}_3)_2\text{PtCl}_6$	$(\text{NH}_4\text{CH}_3)_2\text{SnBr}_6$
1	7.352 Å	7.300 Å	7.383 Å
2	7.355	7.306	7.417
3	7.309	7.306	7.396
4	7.353	....	....
5	7.326	....	....
Average d_{111}	7.34 Å	7.31 Å	7.40 Å
(110) Spacing for			
	$(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$		
1	5.395 Å		
2	5.399		
3	5.399		
4	....		
5	....		
	5.39 Å		

The crystallographic symmetry¹ of each of these three compounds is 3Di, the holohedry of the rhombohedral division of the hexagonal system. For the chlorostannate the angle between the conventionally chosen rhombohedral axes has been measured as $\alpha' = 81^\circ 35'$; for the chloroplatinate it is $\alpha' = 79^\circ 52'$. Though no crystallographic measurements have been published for $(\text{NH}_4\text{CH}_3)_2\text{SnBr}_6$, its symmetry properties do not depart far from those of the other two. The crystallographically determined α' for $(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$

¹ Hjortdahl, Zeit. f. Krist., 6, 466, 1886; Ries, ibid., 36, 346, 1902; P. Groth, Chemische Kristallographie, I, 492, Leipzig, 1906.

differs appreciably from and probably is not as accurate as the $\alpha' = 80^\circ 40'$ arising from the spacing data of Table I.

Series of Laue photographs from these crystals with the X-rays normal or at small angles to the normal to (111) are very similar to one another. Their usual interpretation and the application of the customary criterion for selecting the fundamental lattice show it to be without doubt the truly rhombohedral Γ_{rh} .

The density² of $(\text{NH}_3\text{CH}_3)_2\text{PtCl}_6$ has been found to be $\rho = 2.510$. Calculation of m , the number of molecules in a unit rhombohedron having $\alpha' = 79^\circ 5\frac{1}{2}'$ and $d_{111} = 7.31\text{\AA}$ yields $m = 3.85$. Interpretation of Laue data in terms of a four-molecule cell shows that it is not the true unit. The one molecule cell with axes equal in length and position to one-half the face diagonals of this rhombohedron explains all the reflections obtained from both the chlorostannate and chloroplatinate. For $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ the angle α between these new axes is $50^\circ 14'$; the length of the edge of this rhombohedron is $a_0 = 8.42\text{\AA}$.

Two space groups having the symmetry of the point group 3Di are built upon a rhombohedral lattice. One of these, 3Di-5, has the equivalent positions required for placing one molecule of $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ within the unit; the other, 3Di-6, has room for two molecules.

The question of selecting the correct atomic arrangement in these crystals is identical with that presented by the earlier studied³ $\text{K}_2\text{Sn}(\text{OH})_6$. In both instances two-molecule cells based upon 3Di-6 and one-molecule cells derived from 3Di-5 give the same positions for all except the electronegative atoms (chlorine or hydroxyl). A distinction between these two types of structure must therefore depend upon reflections due to these atoms alone. Although the diffraction data from the chlorostannate, and from the chloroplatinate as well, are in complete accord with the one-molecule cell, it might be thought that the chlorine atoms are insufficient to produce observable reflections. This uncertainty was removed through the analysis of Laue photographs of $(\text{NH}_3\text{CH}_3)_2\text{SnBr}_6$. Three and four-day exposures were used to bring out any faint reflections that might be present. No evidence was found in these results for the two-molecule unit. It must therefore be concluded that an arrangement based upon 3Di-5 is correct.

² Ries, op. cit.

³ Wyckoff, R. W. G., this Journal, 15, 301, 1928.

The atoms in this rhombohedron have one of the following groupings:⁴

- Sn or Pt atom: (a) 000
 N and C atoms: (e) uuu ; $\bar{u}\bar{u}\bar{u}$
 Cl or Br atoms: (f) $u\bar{u}0$; $\bar{u}0u$; $0u\bar{u}$; $\bar{u}00$; $u0\bar{u}$; $0\bar{u}u$.
 or (g) $u\bar{u}\frac{1}{2}$; $\bar{u}\frac{1}{2}u$; $\frac{1}{2}u\bar{u}$; $\bar{u}\frac{1}{2}\bar{u}$; $\frac{1}{2}\bar{u}u$; $\frac{1}{2}uu$.
 or (h) $uu\bar{v}$; $u\bar{v}u$; $\bar{v}uu$; $\bar{u}\bar{u}\bar{v}$; $\bar{u}\bar{v}\bar{u}$; $\bar{v}\bar{u}\bar{u}$.

On account of the comparatively slight scattering powers of the nitrogen and carbon atoms, a selection from these three structures is readily made, using the intensities of different orders of reflection from the base (111).⁵ The relative intensities of these spectra are recorded in Table II. They

TABLE II.

Structure Factors of (111) Reflections for Several Values of $2u + v$.

$2u + v$	Structure Factor for n =					
	1	2	3	4	5	6
	For $(\text{NH}_4\text{CH}_3)_3\text{SnCl}_4$					
0.15	109.9	+18.5	-47.0	-32.5	50.0	132.5
.16	104.6	+ 6.6	-51.2	-15.0	81.5	148.8
.17	99.1	- 5.5	-51.8	+ 6.6	109.9	151.1
.18	93.4	-15.0	-48.8	+30.9	132.5	139.4
.19	87.5	-24.3	-42.3	56.4	147.0	115.0
.20	81.5	-32.5	-32.5	81.5	152.0	81.5
Observed Intensity	strong	faint	slightly > 2	very faint	very strong	strong
	For $(\text{NH}_4\text{CH}_3)_3\text{PtCl}_4$					
0.15	137.9	46.5	19.0	4.5	78.0	160.5
.16	132.6	34.6	23.1	13.0	109.5	176.8
.17	127.1	23.4	23.8	34.6	137.9	179.2
.18	121.4	13.0	20.8	58.9	160.5	167.4
.19	115.5	3.7	14.3	84.4	175.0	143.0
.20	109.5	- 4.5	4.5	109.5	180.0	109.5
Observed Intensity	strong	absent	absent	absent	strong	medium
	For $(\text{NH}_4\text{CH}_3)_3\text{SnBr}_4$					
0.15	173.4	-14.9	-149.7	-119.9	50	....
.16	162.5	-39.4	-158.3	- 83.8	114.9	....
.17	151.2	-62.5	-159.6	- 39.4	173.4	....
.18	139.4	-83.8	-153.4	+ 10.7	219.9	....
.19	127.3	-103.1	-140.0	+ 63.2	249.7	....
.20	114.9	-119.9	-119.9	+114.9	260.0	....
Observed Intensity	medium	medium	medium	absent	strong	

⁴Wyckoff, R. W. G., An Analytical Expression of the Results of the Theory of Space Groups (Washington, 1922) p. 157.

⁵All of the planar indices of this paper are in terms of the one-molecule cell.

depart very far from a "normal" decline of intensity with decreased spacing. In structures developed from (f) and (g) the halogen and tin atoms lie in the same (111) planes. Such groupings cannot explain the foregoing basal reflections. For this reason the chlorine or bromine atoms must be in (h) of 3Di-5.

This structure possesses four parameters, one each for the carbon and nitrogen atoms and two for the halogen atoms. Carbon and nitrogen are so light, however, that if the reflection data are properly handled and only large differences in intensity are employed, they may be neglected and the positions of the halogen atoms accurately established. If this is done, the usual structure factor for the tin and chlorine atoms in $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ becomes

$$A = \overline{\text{Sn}} + 2\overline{\text{Cl}} [\cos 2\pi n(hu + ku + lv) + \cos 2\pi n(hu + kv + lu) + \cos 2\pi n(hv + ku + lu)]$$

$$B = 0.$$

The quantities u and v are approximately fixed by an analysis of the spectra from two faces. For this and all subsequent treatment $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ has been chosen because its data are more complete and capable of yielding a more accurate parameter determination. The observed intensities of (111) are explained only if $(2u + v)$ is between ± 0.15 and ± 0.20 . Structure factors for $(2u + v)$ in this immediate neighborhood are listed in Table II together with similar factors calculated for the chloroplatinate and the bromostannate. They all agree qualitatively with observation within the approximate range $2u + v = \pm 0.18 \pm 0.01$. The numbers of Table II have been obtained using atomic scattering powers proportional to atomic numbers. Other calculations show that the foregoing conclusions are unaltered if allowance is made for the known decreased scattering powers of the light atoms at greater angles.

The relative intensities of the first four (110) reflections from $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ are to be found in Table III. Their structure factors have been mapped for all values of u and v such that $2u + v = \text{ca } \pm 0.18$. They show that the only significant regions capable of accounting for the observed intensities are defined by $u = 0.20$ to 0.25 and $v = -0.21$ to -0.31 . Structure factors within this range are given in Table III. From them it is evident that u and v cannot depart far from 0.23 and -0.27 .

TABLE III.

The Structure Factors for (110) Reflections from $(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$.

Parameters		Factor if n =			
u	v	1	2	3	4
.20	— .21	171.1	283.9	281.9	165.1
.21	— .23	163.0	302.2	233.3	185.3
.22	— .25	155.5	311.0	178.8	205.1
.23	— .27	148.8	318.1	124.4	213.9
.25	— .31	137.7	300.7	34.9	165.1
Observed Intensities:		strong	very strong	medium-strong	slightly > 3

The general correctness of these parameters can be confirmed and they can be still further limited through use of the Laue data (Table IV). Of the two reflections $\bar{1}04$ and

TABLE IV.

Typical Laue Data from a Basal Photograph of $(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$.

Indices	Intensity	$n\lambda$
$\bar{1}22$	m+	0.368
023	f+	.265
$\bar{1}23$	v.s.	.444
$\bar{2}13$	f+	.400
$\bar{3}22$	f	.438
$\bar{2}32$	m—	.473
$\bar{2}3\bar{2}$	ff	.406
$\bar{2}23$	f	.508
$\bar{1}04$	s—	.427
$\bar{4}10$	m+	.505
$04\bar{1}$	f	.419
$40\bar{1}$	v.s.	.473
$\bar{1}\bar{1}4$	f	.340
$\bar{1}24$	m	.450
$0\bar{1}5$	ff	.499
$\bar{3}4\bar{2}$	m+	.484
$61\bar{1}$	f	.498
$53\bar{2}$	m	.473

$\bar{3}22$ with the same spacings and the same wave lengths, the former is clearly more intense. The chlorine terms in the structure factors of these two planes for possible values of u and v are listed in Table V. It is obvious that u can scarcely be greater than 0.23 and v than —0.27. Since $110(4)$ is at least as intense as $110(3)$ only if $u \leq 0.22$ and $v \leq \text{ca } -0.25$, the chlorine atoms in $(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$ are in positions defined by the parameters $u = 0.225 \pm 0.01$ and $v = -0.26 \pm 0.01$. This assignment is confirmed by such Laue intensity comparisons as the following: $\bar{2}13 > 23\bar{2}$, $\bar{1}\bar{1}2 < \bar{2}13$, $\bar{1}40 > 33\bar{2}$, $\bar{1}24 > 33\bar{2}$, $0\bar{1}5 < 34\bar{2}$, $225 > 61\bar{1}$, $61\bar{1} < 53\bar{2}$, $4\bar{1}\bar{1} > 223$, $4\bar{1}\bar{1} > 503$.

TABLE V.
Chlorine Terms in the Structure Factors of First Order
Reflections from Planes ($\bar{1}04$) and ($3\bar{2}2$).

Parameters		Term for	
u	v	($\bar{1}04$)	($3\bar{2}2$)
0.225	—0.26	—0.0123	—0.7045
.225	— .27	— .3109	— .5380
.23	— .26	— .0676	— .5431
.23	— .27	— .3681	— .3681
.235	— .26	— .1264	— .3697
.235	— .27	— .4274	— .1890

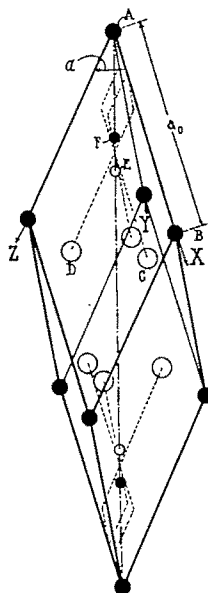


Fig. 1. The unit cell of crystals of $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$, showing the positions occupied by its atoms. The tin atoms appear as large, the carbon as small black circles, the chlorine atoms as large, and the nitrogen atoms as small open circles.

The foregoing analysis proves that the atomic arrangement in crystals of $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ is the following:

$$a_0 = 8.421 \text{ \AA}$$

$$\alpha = 50^\circ 14'$$

Sn atom: 000

Cl atoms: $3\text{Di-5 } (h) \text{ } uuv; uvu; vuu; \bar{u}\bar{u}\bar{v}; \bar{u}\bar{v}\bar{u}; \bar{v}\bar{u}\bar{u}$; with $u = 0.225 \pm .01$ and $v = -0.26 \pm 0.01$.

C atoms: $u_1u_1u_1; \bar{u}_1\bar{u}_1\bar{u}_1$

N atoms: $u_2u_2u_2; \bar{u}_2\bar{u}_2\bar{u}_2$, where u_1 and u_2 cannot be ascertained from the diffraction data. The unit cell of this structure is shown in Fig. 1.

If the crystallographically determined angle $\alpha = 79^\circ 51'$ is taken to be correct, the axial angle of the one-molecule cell for $(\text{NH}_3\text{CH}_3)_2\text{PtCl}_6$ is $\alpha = 48^\circ 46'$, the length of edge is $a_0 = 8.31\text{\AA}$. No crystals of $(\text{NH}_3\text{CH}_3)_2\text{SnBr}_6$ were available with rhombohedral faces large enough for accurate spacing measurements. Since this substance has not been crystallographically described the dimensions of its unit cell are not accurately fixed.

Discussion. Like $\text{K}_2\text{Sn}(\text{OH})_6$ these crystals are conveniently pictured in terms of the crystallographic cell containing four molecules. For $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ its dimensions are $\alpha = 80^\circ 40'$, $a_0' = 11.05\text{\AA}$. From this standpoint the atomic arrangement appears as a CaF_2 , or $(\text{NH}_4)_2\text{SnCl}_6$, structure which has been distorted through elongation of one of the three-fold cubic axes.

The significant interatomic distances in $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ and in the cubic $(\text{NH}_4)_2\text{SnCl}_6$ are compared in Table VI.

TABLE VI.
Significant Interatomic Distances in $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ and in $(\text{NH}_4)_2\text{SnCl}_6$.

Atoms	In $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$	$(\text{NH}_4)_2\text{SnCl}_6$
Sn—Cl	2.44Å	2.46Å
Cl—Cl (same group)	3.43, 3.47	3.48
Cl—Cl (adjacent groups)	3.68	3.64
NH ₃ —Cl (E—D)	3.50	3.57
(E—G)	3.57	...
CH ₃ —Cl (F—G)	3.81	...
(F—H)	3.80	...
NH ₃ —CH ₃	1.32	...

The capital letters in this table refer to atomic designations in Figure 3.

They are practically identical. The SnCl_6 group thus has the same shape and size in both crystals. The probable positions of the carbon and nitrogen atoms of the NH_3CH_3 groups can be found from these interatomic distances. Studies of the structures of the tetra- and the mono-methyl ammonium⁷ halides give the following approximate atomic separations: $\text{CH}_3\text{—Cl} = \text{ca } 3.85\text{\AA}$, $\text{N—C} = \text{ca } 1.35\text{\AA}$, $\text{NH}_3\text{—Cl} = \text{ca } 3.5\text{\AA}$, $\text{NH}_4\text{—Cl}$ [in $\text{NH}_4\text{Cl} = 3.34\text{\AA}$, in $(\text{NH}_4)_2\text{SnCl}_6 = 3.57\text{\AA}$]. Distances as great as these are obtained only in case the CH_3

⁶ Dickinson, R. G., J. Am. Chem. Soc., **44**, 276, 1922.

⁷ Wyckoff, R. W. G., Zeit. f. Krist., **67**, 91, 1928; Hendricks, S. B., *ibid.*, **67**, 106, 1928.

ends of NH_3CH_3 groups point towards the origin. If the methyl radical is $3.80\text{\AA}$ away from three of the chlorine atoms about the tin atom at 000 and if the distance between the NH_3 group and the chlorine atom at $u, u, 1 + v$ (D of Fig. 3) is $3.50\text{\AA}$ then u_1 and u_2 for carbon and nitrogen are 0.21 and 0.27. The nitrogen-carbon distance within the group defined in this way is ca $1.32\text{\AA}$.

It is of interest to inquire whether the parameters found for $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ are the only ones which will give its SnCl_6 group the shape that it has in $(\text{NH}_4)_2\text{SnCl}_6$. The chlorine parameters which satisfy the conditions (1) $\text{Sn}-\text{Cl}=2.46\text{\AA}$, (2) $\text{Cl}-\text{Cl}$ (in the same group) $=3.47\text{\AA}$, (3) $\text{Cl}-\text{Cl}$ (in adjacent groups) $=3.62\text{\AA}$ are plotted in Fig. 2. One other and distinctly different pair of parameters

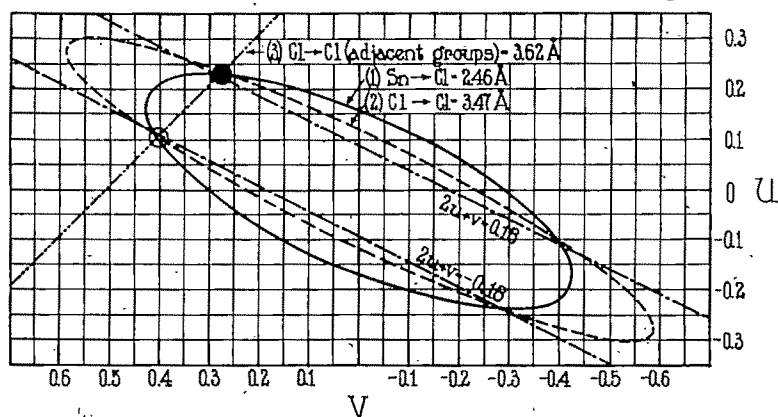


Fig. 2.

besides that deduced in the preceding analysis gives an undistorted SnCl_6 group. This is $u = \text{ca } 0.11$, $v = \text{ca } -0.41$. Not only is this pair in conflict with the intensities from (110) but attempts to fit NH_3CH_3 groups into such a structure show that not enough space is available for them.

The foregoing calculations clearly define several factors which determine the atomic arrangement in these crystals. The interatomic distances which are maintained are those which preserve (1) the shape and size of the SnCl_6 and NH_3CH_3 groups and (2) the known separation of the NH_3CH_3 groups and the chlorine atoms. The SnCl_6 group

appears to remain intact and to have the same essential shape irrespective of the symmetry of the crystal containing it. The chlorine-to-chlorine distance within an SnCl_6 ion is less than that prevailing between neighboring ions. The strong attractions existing between tin and chlorine atoms are thus seen to crowd together the chlorine atoms in SnCl_6 . In this group the resulting distortion is comparatively slight. In others, such as the carbonate ion, it may be very great and the distance between the oxygen atoms of an ion may be small.

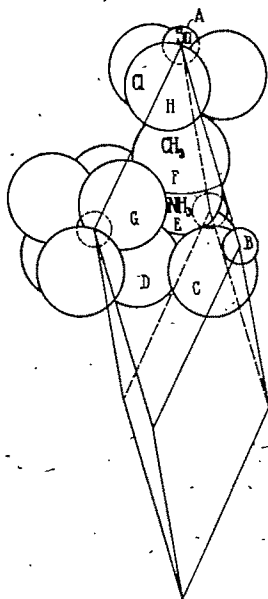


Fig. 3. A portion of the structure of $(\text{NH}_4\text{CH}_3)_2\text{SnCl}_6$ showing how the atoms may pack together. The sizes given to the atoms in this figure are the ones resulting from the assumption of contacting chlorine atoms. The atoms, A, B, C, etc., are the same in this drawing and in Figure 1.

The results of this analysis are in striking agreement with the absolute ionic dimensions deduced from the hypothesis⁸ of contacting oxygen ions in simple salts that contain small positive ions. A portion of the structure showing atoms of the sizes required by this hypothesis is represented in Fig. 3. The radii used are practically the same as those arising from certain theoretical calculations⁹ and have the values Sn^{++++}

⁸ Bragg, W. L., and Brown, G., Proc. Roy. Soc. A, 110, 34, 1926.

⁹ Pauling, L., J. Am. Chem. Soc., 49, 765, 1927.

$= 0.65\text{\AA}$, $\text{Cl}^- = 1.81\text{\AA}$, $\text{NH}_3 = 1.62\text{\AA}$, $\text{CH}_3 = 2.04\text{\AA}$. A layer-like atomic arrangement parallel to basal planes is manifest. The NH_3CH_3 ions are imbedded in sheets of SnCl_6 groups which touch one another and both the NH_3 and the CH_3 radicals. Parallel sheets are held a considerable distance apart by the larger and protruding CH_3 portions of the positive ions.

This picture is important in its bearing upon the structure of the cubic $(\text{NH}_4)_2\text{SnCl}_6$. The chlorine parameter in this crystal is such that it scarcely departs from a close packing of chlorine atoms with ammonium ions and tin atoms lying in the interstices. The present results, as well as to a certain extent the structures^{10,11} found for $(\text{NH}_4)_2\text{SiF}_6$ and Cs_2GeF_6 show that such a packing is not the determining factor for a CaF_2 -like grouping.

The atomic arrangements in $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ and in $\text{K}_2\text{Sn}(\text{OH})_6$ depart from a cubic symmetry for different reasons. For $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ it is presumably due to the elongated character of the NH_3CH_3 group. Though the causes operating for $\text{K}_2\text{Sn}(\text{OH})_6$ are not so well known, they appear to reside partly in the small size of the potassium atoms and partly in the fact that hydroxyl is not of itself large enough to maintain an $\text{Sn}(\text{OH})_6$ group of the requisite symmetry.

Summary. The atomic arrangement in crystals of $(\text{NH}_3\text{CH}_3)_2\text{SnCl}_6$ has been obtained from a study of Laue and spectrum photographs. This atomic grouping is a distortion of the CaF_2 structure. Its unit cell, containing a single molecule, has the dimensions: $\alpha = 50^\circ 14'$, $a_0 = 8.42\text{\AA}$. The tin atom in this cell is at 000, the chlorine atoms at 3Di-5(h) with $u = 0.225 \pm 0.01$ and $v = -0.26 \pm 0.01$. Carbon and nitrogen atoms are at 3Di-5(c) with u_c and u_n probably equal to 0.21 and 0.27. Crystals of $(\text{NH}_3\text{CH}_3)_2\text{SnBr}_6$ and $(\text{NH}_3\text{CH}_3)_2\text{PtCl}_6$ have very similar arrangements. In $(\text{NH}_3\text{CH}_3)_2\text{PtCl}_6$ the single-molecule cell has the dimensions $\alpha = 48^\circ 46'$, $a_0 = 8.31\text{\AA}$. The general character of these structures is discussed in terms of the interatomic distances they display.

ROCKEFELLER INSTITUTE FOR MEDICAL RESEARCH,
NEW YORK, N. Y.

¹⁰ Bozorth, R. M., J. Am. Chem. Soc., **44**, 1066, 1922.

¹¹ Wyckoff, R. W. G., and Müller, J. H., this Journal, **13**, 347, 1927.

DISCUSSION AND COMMUNICATIONS.

NEW EROSIONAL TERMS.

The new terms recently proposed by W. S. Glock (An Analysis of Erosional Terms: This Journal, June, 1928, pp. 471-483), for certain processes of erosion and deposition, invite comment on their clarity of meaning. Although even purely artificial words occasionally are adopted, the writer thinks that the alteration of accepted word roots is to be discouraged. In the term *eoposition* suggested by Glock as a contraction for eolian deposition the eolian part of the compound is unduly shortened by the omission of the letter *l*. *Eo*, from the Greek word meaning "dawn" (or by association "early"), is already in use as a prefix in English words such as Eocene, eolith, Eozoon and Eohippus, so that *eoposition* suggests a Greek-Latin hybrid meaning "early position," a place. To prevent any confusion the full *eoli*—from Aiolus (Greek) or Aeolus (Latin) is necessary. His term *eolation* meets that requirement satisfactorily.

The term *blastation* involves a similar confusion of possible meanings, inasmuch as the prefix *blast* or *blasto-* (from the Greek word *blastos* meaning shoot or bud) is used in such words as blastoid, blastema and blastoderm, so that *blastation* might be interpreted to mean the process of sprouting or developing buds. Linguistic purists may object that the term proposed is a hybrid regardless of whether the Anglo-Saxon or Greek "blast-" is intended. Several hybrids are in common use, however, and purity of etymology is a secondary matter. Since the prefix "blast-" is preempted already by the Greek root with a different meaning, the term *blastation*, in spite of the original intention of its author, becomes subject to misinterpretation and therefore should be dropped.

In the terms *glarosition*, *glaposition*, *flurosion*, *fluposition*, *plurosion* and *pluposition*, the elision of the last letters of the prefixes obscures the identities of the roots and therefore the meanings of the compounds. It also tends in some cases toward a harshness of sound. *Flurosion* suggests flow-gnawing rather than stream-gnawing. *Plurosion* may suggest the root *plus* or *pluri-* (Latin for "more"), as in plural and pluperfect. Without the "v" *plu* to the reader may stand for plume, plus or Pluto just as well as for pluvius. *Marosion* has fewer resembling forms and is less objectionable. The writer suggests that in forming words with these roots the full spelling "fluvi(o)," "glaci(o)" and "pluvi(o)" be retained, even at the expense of an extra syllable or two. Terms intended for technical use by advanced students and specialists should be no less clear than those intended for general use.

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HALITE AND GLAUBERITE CAVITIES IN THE TRIASSIC ROCKS OF CENTRAL NEW JERSEY.

Some new evidence bearing upon climatic conditions in central New Jersey during early Triassic time has recently come to light. The recent paper by Percy E. Raymond¹ dealt with this subject in its broader phases; earlier writers whose observations are particularly important in this connection include B. K. Emerson² and E. T. Wherry.³

Professor Emerson, in 1895, reported cavities representing halite crystals, some of them filled with calcite, at West Springfield, Wilbraham, and Holyoke, Massachusetts, in sediments of Triassic age. And, so far as the present writer has observed, they have never been reported in this formation at any point farther south. Wherry (op. cit.) reported numerous excellent glauberite crystal cavities in the Triassic of Pennsylvania.

Massive red shales in the lower part of the Triassic formation, which are weathering in the roadside just at the west end of the wall at the new Johnson estate along the river road on the north bank of the Raritan a mile above New Brunswick, New Jersey, have afforded to date two excellent cavities of halite crystals. Both of these are hopper-shaped, over 2 cm. across the open end and 3 cm. deep, one showing a small cube face at the acute end. Their form is that of the crystals from the Salina of New York, though their inner surface is quite smooth and not stepped. Hopper-shaped halite crystals have apparently not before been observed in the Triassic, all of the crystals seen in Massachusetts having been cubes. The cavities at New Brunswick are entirely empty.

Cavities similarly representing glauberite crystals have often been observed in New Jersey⁴ and Pennsylvania,² but the remarkable abundance of them in the red shales has apparently not been recognized. The cavities are often diamond-shaped in outline, the crystals showing a combination of base *c* and unit pyramid *s*, and average about 1 x 1 cm. in size. So completely do they fill certain layers that these layers are quite porous. At various points in the Triassic Lockatong beds, radiations of glauberite crystal cavities extend downward for several feet (Hawkins, op. cit.). Near the west side of the Johnson & Johnson works in New Bruns-

¹ Raymond, P. E., Significance of Red Color in Sediments; This Journal, 13, 234-251, 1927.

² Emerson, B. K., A Mineralogical Lexicon of Franklin, Hampshire, and Hampden Counties, Massachusetts; U. S. Geol. Survey Bull. 126, p. 144, 1895.

³ Wherry, E. T., Glauberite Crystal Cavities in the Triassic Rocks of Eastern Pennsylvania, American Mineralogist, 1 (13), 37-43, Plate III, Fig. 1, 1916.

⁴ Hawkins, A. C., The Lockatong Formation of the Triassic of New Jersey and Pennsylvania; Annals N. Y. Acad. Sciences, 22, 145-176, 1914.

wick, and again on the east side of the river in Highland Park, the cavities, which are abundantly bunched together in what were once groups of glauberite crystals in the muddy layers, are lined with small white calcite crystals, whose form is a combination of the obtuse rhombohedron *e* with the unit prism *m*. Also many of the cavities contain, with the calcite, white tabular barite crystals showing numerous lines of "phantom" growth. The forms shown by these crystals are, base *c*, unit prism *m*, unit brachydome *o*, obtuse macrodome *d* [102], and brachypinacoid *b*. The largest barite crystal recently found measured 1.5 x 2 cm. Some are arranged in rosettes. Their origin is likely to have been connected with that of the copper minerals which were mined in this immediate vicinity during Revolutionary times. Similar deposits of barite, on a larger scale, exist at Glenmoore, New Jersey, and in Prospect Park, Paterson.

At a little quarry along the Delaware & Raritan canal just east of the bridge at Blackwells Mills, New Jersey, the filling of calcite crystals (here scalenohedral in habit) lining the glauberite cavities is so complete and firm that the shale on the outside breaks away from the cavity fillings, so that we obtain complete calcite pseudomorphs after the glauberite crystals (compare Wherry, Fig. 1). These pseudomorphs may be picked up out of the loose weathered red shale. They average 1 to 3 cm. long by 1 to 2 cm. wide, but some very large simple crystals occur, 10 cm. by 5 cm. and larger. The possible influence of igneous action in the filling of these cavities may be considered, since there is a diabase dike cutting vertically across the shales a quarter of a mile to the north. This Blackwells Mills locality is six miles north of the well-known Griggstown copper mine, where the effects of the intrusion of the thick diabase of Rocky Hill (the Palisade sill) are widespread.

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SCIENTIFIC INTELLIGENCE.

CHEMISTRY.

By-Products in the Packing Industry; by RUDOLF A. CLEMEN. Pp. 410. Chicago, 1927 (The University of Chicago Press, price, \$4.00).—The packing industry exemplifies, to a remarkable degree, the economic importance of by-products, the production of which has been developed by the packing companies to an extent which is probably not excelled by any other industry. It is this interesting commercial development, with its many ramifications, which Mr. Clemen ably presents, with the collaboration of several well-known specialists.

Among the more important topics which are covered in this book are hides, skins, wool, hair, fats, soaps, glues, gelatine, fertilizers, and pharmaceuticals. An interesting viewpoint of the management of by-product manufacture is also given. Although there is comparatively little chemistry in this book, there is much to hold the attention of the chemist, by reason of the picture it gives of the opportunities for application of chemical science. Thus, the chapter on pharmaceuticals is peculiarly timely, and indicates in clear fashion the interesting future possibilities of by-product manufacture for the alleviation of human suffering with increase in knowledge of the chemistry of ductless glands. It is not a text-book of "industrial chemistry," as it gives neither a detailed account of many of the operations, nor, in general, pictures, or drawings, of necessary apparatus. However, it is a very readable and interesting book, and is a useful source of reference, with its excellent statistical information, and its authoritative discussion of certain topics.

A. J. HILL.

A New Method of Extinguishing Fires.—Combustion, which we call fire when it proceeds sufficiently rapidly, is of course a chemical reaction and is subject to the laws governing such reactions. In order to maintain combustion, three factors are required: fuel, oxygen, and a temperature above a certain minimum called the kindling temperature. Although union of a substance with oxygen may take place below the kindling temperature, we do not have a fire in such cases. Conversely, if any one of these essentials is removed, the fire must go out. Now in extinguishing a real out-of-control fire, such as a burning building, it is obviously impossible to withdraw the fuel, and all our efforts towards extinguishing such fires are directed either toward lowering the temperature below the kindling point or shutting off the oxygen supply. Playing water on a fire produces largely the first of these effects, and if the heat is too extreme—as in the case of oil fires—it fails. Carbon tetrachloride, which is effective in oil fires, puts them out by blanketing the flames, that is, shut-

ting off the air. Until THOMAS and HOCHWALT recently discovered their so-called catalytic effect, these were the only known methods of putting out fire.

These investigators found, apparently by accident, that a strong solution of sodium-potassium carbonate sprayed on burning gasoline extinguished the blaze almost instantly. This effect was so startling that they carried out an extensive investigation of the action of aqueous salt solutions on oil fires, and found that a large number of compounds had a similar effect. The best inhibitors proved to be salts of the alkali metals (such as sodium and potassium), but the negative radical of the salt also played an important part, those containing oxygen being most effective. No real explanation of this effect is advanced and it should be understood that the term "catalytic" is used merely as a term, not as an explanation.

Small extinguishers employing such salt solutions are on the market and have proved more effective on small fires (both oil and wood) than any previously known type. They possess a decided advantage over the carbon tetrachloride type—"pyrene"—in that no obnoxious fumes are given off when they are used.

Ind. Eng. Chem., 20, 575, 1928.

E. B. K.

Cellulose Resources: Steps toward Conservation.—In a series of three articles (*Ind. Eng. Chem.* 20, 494, 587, 716, 1928), GEORGE M. ROMMEL presents an excellent survey of our cellulose resources. This country has long been noted for her prodigal use of wood and for her careless waste of a considerable portion of the forest cuttings. It is good to learn from these articles that there is a decided trend toward conservation—not so much in less cutting of forests, but rather in reforestation and in the utilization of much that was formerly wasted. At present much of the wood waste goes into paper, wall board, and insulating lumber, but efforts are being directed toward enlarging the field of recovered products. The articles mentioned do not readily lend themselves to abstraction, and will be found worth reading in their entirety, since they are not technical. The first deals with the annual wood crop, the second with the production of cellulose from field crops, such as corn, and the third is an analytical survey of the costs of obtaining cellulose from the various crops.

In this connection it is interesting to note that a large pilot plant for deriving cellulose products from corn stalks is in operation in the midst of the Illinois corn fields. The baled stalks, received at the factory, are fed through cutters and shredders and leached with hot water to remove fermentable carbohydrates of commercial value. The resulting fibre is digested with caustic and bleached, after which it may be made into paper. The caustic liquors are worked for the recovery of pentosans which have value in the lacquer industry. It is the intent to recover every possible by-product.

The future of this branch of the cellulose industry would seem bright. At present corn stalks are usually burned or plowed under. Since they have little fertilizing value and are of course totally wasted if burned, some use for them should be welcomed by the farmer, especially since he must clean up his fields if the corn borer is to be controlled. *Ind. Eng. Chem.*, News Edition, 6, No. 10.

E. B. K.

GEOLOGY.

Landslide Lakes.—H. J. RUSSELL has recently described two extinct landslide lakes, one in northwestern Nevada, the other in northeastern California.* In each case, a local basin, formed by the faulting of lava blocks, was drained antecedent fashion by a river that aggraded the basin and trenched a canyon through its upfaulted barrier; in each case, the canyon was blocked by a landslide; whereupon a lake rose behind it. In the Nevada example, which occupied High Rock valley, the lake overflowed not across the landslide in the canyon but across a sag in the up-faulted block 3 miles to the north; and there a second canyon was cut down to within 50 feet of the present basin floor. Overflow then ceased, as if by reason of increasing aridity, and the basin now has no outlet. In the California example, which occupied Jess valley on the back or western slope of the great Warner range fault-block, Pitt river, a head branch of the Sacramento, overflowed across the obstructing landslide and, trenching it, discharged the lake. The lake bed, a flat floor, is still drained by the river. This suggests that relatively small rivers can maintain their courses against upfaulting lava blocks but not against down-falling landslides.

W. M. D.

A Catalogue of the Mesozoic Mammalia; by GEORGE GAYLORD SIMPSON. Quarto. Pp. x, 215, 12 pls., 55 text figs. London, 1928 British Museum of Natural History. This fine monograph in its typography and general appearance is worthy of the great institution which it represents. The author, who was for several years a student and research fellow at Yale University, has had opportunity to study in America all of the mammals pertaining to the Mesozoic Formations, which are, for the most part, contained in the Peabody Museum at Yale and the U. S. National Museum, the Marsh Collections; besides that in the American Museum of Natural History, and other lesser collections. To this study he brought a keenly analytical mind, untrammelled by preconceived notions, which resulted not only in a most exhaustive and discriminative study of these minute forms but in the development of a new technique in their preparation and illustration. Not only

* Landslide lakes of the northwestern Great Basin. Univ. Calif. Pubs. in Geogr., vol. 2, 231-254, 1927.

were the old species redescribed, but a vexatious synonymy, which necessarily arises when specimens so fragmentary are concerned, was unraveled and a new classification (which has already had authoritative acceptance), was proposed; this includes not only family description but the erection of at least one new order.

With this as a background Dr. Simpson approached the Old World material, basing his studies upon that contained in the British Museum collections, supplemented by that in the continental museums and in the Yale Museum, which fortunately contained some European types.

An historical sketch tells, in a critical fashion, of the previous work done on the Mesozoic mammals, after which the systematic descriptions follow. One of the most interesting sections tells of the relationships of the orders, each of which is clearly diagnosed, and a diagram summarizes the author's view of these relationships and is a marked departure from any hitherto held.

Of the existing major mammalian groups the Monotremata, so often spoken of as of Mesozoic affinities, have no connection whatever with any known Mesozoic orders. Indeed nothing at all is known of their ancestry before the Pleistocene. The Marsupials and Placentals are derived, without direct evidence, from the stem that gave rise to the Pantotheria (= Trituberculata), so that the order of Pantotheria represents the ancestry of both marsupials and placentals, without itself belonging to either group. Both the Triconodonta and Multituberculata are isolated orders which terminate without further issue. The latter does, however, survive the Mesozoic before its final extinction. In this it is unique among Mesozoic mammals. The derivation of the mammals from the Cynodont reptiles is now generally accepted; Dr. Simpson's diagram implies a multiple origin for the class, however.

A very interesting discussion of the English stratigraphy follows, with an attempt at correlation of these with the American mammal-bearing horizons, the faunal comparison of the Purbeck and Morrison being of especial significance, as is also a complete British faunal list. The list of works consulted contains all the original contributions to our knowledge of European Mesozoic mammals, omitting the almost innumerable works which touch upon the group without adding anything to the current knowledge concerning them.

Taken collectively, Dr. Simpson's works, consisting of a number of separate papers, his forthcoming memoir on the American forms, and now this present publication, will give an authoritative point of departure for all subsequent work on the entire Mesozoic mammalian fauna. Further profitable work can only be done as a result of new discoveries.

R. S. L.

Permian Fossil Insects of North-east Europe; by A. MARTYNOV. Trav. Musée Géol. Acad. Sci. U. R. S. S. Vol. 4, pp. 1-118, pls. 1-19, 3 text figs., 1928.—From this work we learn that

the Upper Permian of Russia has so far yielded 62 forms of insects. Of these, 16 are old species, and 46 new ones are here added, in 35 genera (29 new). The material is well preserved, all wings. We are surprised to note the presence of three Palaeodictyoptera so late in the Permian. Most of these new forms were found in two concretions that also had land plants and *Lingula*. The author says that about one fourth of these insects were clearly descended from European Upper Carboniferous forms, that one third are allied to those of the Lower Permian of North America, and that the rest are of local origin. c. s.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

The People of the Twilight; by DIAMOND JENNESS. Pp. xiv, 245; frontispiece, 17 photographs, 2 maps. New York, 1928 (The MacMillan Company, \$3.00).—As a member of a scientific expedition to the Arctic the author employed a rare opportunity to live for two years among the primitive Eskimos of the Coronation Gulf Region. Much of this period was spent with a single family with whose members the reader became well acquainted. Their struggle to exist through the severity of the winters, as well as their shorter seasons of pitiful "plenty" in summer, are pictured with unusual clearness. Above all, the simple friendliness and affection of this family toward its adopted son is expressed in a way vividly to reveal the brotherhood of man. Naturalists of all degrees will find many fresh notes on the fauna and flora of the region about the mouth of Coppermine River, in the waters of Coronation Gulf, and on southwestern Victoria Island. Particularly instructive are the references to caribou. Anthropologists will find much of interest in the author's description of the material culture and behavior of the Eskimos as seen during the year's cycle in search of food and materials.

S. C. B.

PUBLICATIONS RECENTLY RECEIVED.

History of the Sheffield Scientific School of Yale University, 1846-1922; by Russell H. Chittenden. Two vols. New Haven, 1928 (Yale University Press, \$10.00).

The Development of the Human Eye; by Ida C. Mann. Cambridge, 1928 (The Macmillan Company, American Agents).

The Social Insects. Their Origin and Evolution; by William M. Wheeler. New York, 1928 (Harcourt, Brace & Co., \$7.00).

Forty-second Annual Report of the Bureau of American Ethnology, 1924-1925. To the Secretary of the Smithsonian Institution. Washington, D. C., 1928 (The U. S. Government Printing Office).

Solubilities of Inorganic and Organic Compounds. Supplement to Second Edition; Atherton Seidell. New York, 1928 (D. Van Nostrand Co., Inc., \$8.00).

Elements of Optical Mineralogy; by Alexander N. Winchell. Third Edition; Part I, Principles and Methods. New York, 1928 (John Wiley & Sons, \$3.50).

Food Products, Their Source, Chemistry and Use. Third Edition; E. H. S. Bailey and Herbert S. Bailey. Philadelphia, 1928 (P. Blakiston's Son & Co., \$2.50).

A First Course in Physics for Colleges; by Robert A. Millikan, Henry G. Gale and Charles W. Edwards. Boston, 1928 (Gill and Company, \$3.72).

Colloid Chemistry; by The Svedberg. Second Edition. New York, 1928 (Chemical Catalogue Co., \$5.50).

Toxicology or The Effects of Poisons; by Frank P. Underhill. Second Edition, revised, enlarged. Philadelphia, 1928 (P. Blakiston's, \$2.50).

Ernst Brücke; by E. Th. Brücke. Vienna, 1928 (Verlag Von Julius Springer, M. 9.60).

Bibliography of Crystal Structure; by Jared K. Morse. Chicago, 1928 (University of Chicago Press, \$3.00).

American Chemistry; Harrison Hale. Second Edition. New York, 1928 (D. Van Nostrand Co., Inc., \$2.50).

Creation of Evolution; edited by Frances Mason. New York, 1928 (The MacMillan Co., \$5.00).

The Cave Man's Legacy; by E. Hanbury Hankin. New York, 1928 (E. P. Dutton Co.).

Engineering Chemistry. Sixth Edition; by Thomas B. Stillman, revised and enlarged by Albert L. Stillman. Easton, Pa., 1928 (The Chemical Publishing Co.).

The Collected Works of J. Willard Gibbs. Volume I. Thermodynamics. Volume II, Statistical Mechanics, Dynamics, Vector Analysis Light, etc. New York, 1928 (Longmans, Green & Company, \$6.00 set).

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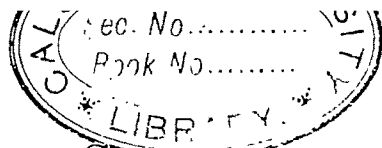
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AMERICAN JOURNAL OF SCIENCE

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THE ANALYTICAL DETERMINATION OF URANIUM, THORIUM, AND LEAD AS A BASIS FOR AGE-CALCULATIONS.

CLARENCE N. FENNER.

The radioactive disintegration of uranium and thorium, with the formation of lead as a final product, is now held to be well established, and, in principle, the possibility of determining the age of minerals by the ratio of lead to uranium and thorium is generally accepted. In the practical application of the method, however, a number of difficulties and uncertainties enter. It is not the intention to discuss these as a whole in this article, but to confine attention to the matter of analytical determination of these elements.

There is a considerable literature on the subject, but much of it is not well systematized, nor formulated to meet the somewhat special requirements demanded in age-determinations. Moreover, some of the methods appear to be applicable only under certain conditions, while their limitations are not stated in the description given.

There is also on record a fairly large and increasing number of analyses made for the purpose of age-determination. Among these some are undoubtedly of a high order of accuracy, while others lead to results which appear improbable. Analytical accuracy is one of the most fundamental of the factors entering into the calculation of geologic age.

In the course of a rather large amount of work on the subject I have investigated a number of methods of analysis which appeared favorable. Some have been found to require special apparatus or technique, or unusual reagents; others are suspected to be not wholly dependable. By a process of selection and elimination procedures have gradually been evolved which seem to give consistent and reliable results. During this investigation and experimentation I have had the benefit of correspondence and discussion with Dr. H. V. Ells-

worth, of the Canadian Geological Survey; Dr. M. F. Connor, formerly of the Canadian Geological Survey; and Dr. R. C. Wells, of the U. S. Geological Survey. From these gentlemen I have received valuable suggestions, which have been incorporated in the final schemes. These schemes are offered, not with the expectation that they will be found entirely free from faults, but rather with the hope that they will be found, in their fundamental features, sound and practicable and not unusually difficult of application, and that not more than small modifications will be required to make them entirely acceptable.

It should be borne in mind that in making analytical determinations to serve as a basis for age-calculations errors which would not be looked upon as at all serious in ordinary rock analysis may invalidate the results completely. In work with minerals of this kind, therefore, it is highly desirable that the single purpose of accurate determination of uranium, thorium, and lead be kept in mind, and that the determination of other constituents be made on another portion of the sample if there is any possibility that in their determination the accuracy of the uranium-thorium-lead determinations might be sacrificed in any degree. The schemes have been devised wholly on the basis of the uranium-thorium-lead determination; at the same time it will probably be found that most of the other constituents can be determined in the same portions.

There is a great variety of uranium and thorium minerals, and the analysis of some of these is not difficult. The greatest difficulties appear in two common classes, which may be typified by euxenite and monazite. In such minerals as euxenite, polycrase, and samarskite, large quantities of titanium, tantalum, and columbium oxides are present, and after the mineral is first brought into solution, practically no step of procedure can be taken without causing hydrolysis of these three earths, and in the great bulk of hydrolytic precipitate formed large amounts of uranium and thorium will be adsorbed or occluded, even in acid solutions.

With monazite the chief difficulty is caused by the presence of phosphoric acid, which tends to precipitate thorium and rare earths at undesirable points unless it is eliminated at an early stage.

With minerals of more simple constitution appropriate modifications may be made. Such minerals as zircon, however, will require special treatment, and not much attention has yet been given to these, but the easy solubility of zirconium

oxalate in an excess of oxalic acid seems to offer a ready means of getting rid of zirconium.

*Determination of Uranium and Thorium in Euxenite,
Polycrase, Samarskite, Etc.*

Take for analysis 2 or 3 grams of powdered mineral. Add 5 times as much sodium bisulphate, and fuse at bright red until evolution of sulphuric anhydride nearly ceases. Cool, and add an amount of sulphuric acid equal in cubic centimeters to the weight in grams of sodium bisulphate taken (or a little less). Digest for $1\frac{1}{2}$ hours at heavy fumes of sulphuric anhydride. Cool, and dissolve in cold water. Transfer to beaker and let stand over night. Disregard precipitate.

The solution containing the precipitate is divided into aliquot parts on the basis of the sulphuric acid used in digestion, in such a manner that one portion contains about 5 cc. free sulphuric acid. The other portion is approximately neutralized with solid sodium carbonate, and the two portions are reunited. Make volume 450 cc. and boil vigorously for one-half hour. Let hydrolyzed precipitate of titanium, tantalum, and columbium oxides settle on steam bath, and filter. Wash with hot water. Remove as much as possible of precipitate from filter with platinum spatula, and place in a solution of 50 cc. nitric acid: 150 cc. water. Boil a little, and filter through same filters as before.

The two filtrates (kept separate) are evaporated to less bulk. If a little precipitate forms in the sulphuric acid solution it is disregarded. Add to this solution ammonia in small excess, boil, and filter; wash with hot two per cent ammonium nitrate. Dissolve the precipitate with the nitric acid filtrate obtained from digestion of hydrolysis precipitate. Set solution aside for additions.

The filtrate from ammonia is evaporated to small bulk, cooled, and a little more ammonia added. There may be a small additional precipitate. Filter, wash with a little cold two per cent ammonium nitrate, dissolve precipitate in nitric acid, and add to previous nitric acid solution. Reject the filtrate from ammonia.

The combined precipitates of titanium, tantalum, and columbium obtained from hydrolysis are dried and ignited, and fused with five times their weight of sodium bisulphate,

and the subsequent procedure carried out as before; and finally a third fusion and subsequent operations are performed. By this repetition the occluded uranium and thorium carried down by the bulky hydrolysis precipitates are brought into solutions free from titanium, tantalum, and columbium.

The combined nitric acid filtrates are boiled to expel any possible carbon dioxide. Make rather strongly ammoniacal, and boil. Filter, and wash with hot two per cent ammonium nitrate. Wash the precipitate from the filter into a gold or platinum basin, and wash the filter with hot, dilute hydrofluoric acid ($10 \pm$ cc. hydrofluoric acid) into same basin. The filter is ignited in a platinum crucible, in which the filter papers of the immediately subsequent fluoride filtrations are likewise to be ignited. The filtrate from the ammonia precipitation is evaporated to small bulk, and cooled. To cold solution a little ammonia is added. A small amount of white precipitate will probably form, which is to be filtered off and converted into fluoride as before, and united with main portion.

The solution containing the precipitate of fluorides of thorium and rare earths is evaporated to small bulk. The precipitate becomes granular. Dilute and filter (using hard rubber funnel), and wash with dilute hydrofluoric acid. The filtrate is set aside for uranium determination.

The precipitate of fluorides is washed from the filter into a platinum basin, and a few cubic centimeters of sulphuric acid added. The solution is evaporated to fumes of sulphuric anhydride, and the precipitate digested until the fluorides are converted into sulphates. The trace of fluoride precipitate left on filter is ignited in the crucible containing the ash of the immediately preceding filters, and is fused with a very little sodium bisulphate and digested with sulphuric acid. This is taken up with water, and added to the main sulphuric acid solution of thorium and rare earths. When the material has dissolved, the solution is partly neutralized with solid sodium carbonate, leaving 3-4 cc. free sulphuric acid. Any precipitate that forms is disregarded (but keep solution distinctly acid). Make volume 200-250 cc. Add the solution, drop by drop, to 200 cc. of a cold saturated solution of oxalic acid containing 10-15 grams excess of oxalic acid crystals, stirring repeatedly. Set on steam bath for several hours, and let stand cold over night. For further treatment for recovering thorium see determination of thorium in mona-

zite. The procedure is to convert this oxalate precipitate into nitrate, and precipitate the thorium three times as peroxyferate and once more as oxalate.

The filtrate from the hydrofluoric acid precipitation of thorium and rare earths contains all the uranium. It is evaporated with 5-6 cc. sulphuric acid to fumes of sulphuric anhydride, and diluted with water. Neutralize with sodium carbonate, and add 2-3 grams excess of the crystals. Make volume about 400 cc., and boil for a few minutes. Filter, and wash with hot two per cent ammonium nitrate. Dissolve the precipitate in nitric acid, and repeat the precipitation with sodium carbonate. Filter. Reject second precipitate. Combine the sodium carbonate solutions, and acidify with nitric acid. Boil out all carbon dioxide. Add considerable excess ammonia, boil, and filter. Wash with two per cent ammonium nitrate. Reject filtrate. Dissolve precipitate of uranium in nitric acid, and make ammoniacal in the cold. Add to it (as little as is necessary to dissolve the uranium) a solution made up by dissolving $3 \pm$ grams ammonium carbonate in water containing 5 cc. strongest ammonia. Let stand 2-3 hours. If a small residue remains, filter off and reject. Heat the carbonate solution until most of the carbon dioxide and ammonia is driven off, make faintly acid with nitric acid, and boil off all carbon dioxide.¹ To hot solution add ammonia in slight excess, filter, and wash with hot two per cent ammonium nitrate. Ignite strongly the precipitate of uranium and weigh as U_3O_8 . As it may contain a trace of silica and alumina it is dissolved in warm 1:1 nitric acid, and the little residue is filtered off, ignited, and weighed; and subtracted from the U_3O_8 found.

As an additional refinement, it would be well to test for traces of iron, titanium, tantalum, columbium, and zirconium in the last nitric acid solution by converting it into a dilute sulphuric acid solution, and adding a little freshly filtered solution of cupferron (ammonium phenylnitrosohydroxylamine). If there is any precipitate, ignite and weigh, and subtract from the U_3O_8 found.

¹ If vanadium is suspected to be present, it may be removed at this point as lead vanadate in an acetate solution. Metals of the hydrogen sulphide group may also be precipitated here, though they (except lead) are hardly to be expected in material which is suitable for age-determinations. If hydrogen sulphide is passed, the solution should be oxidized again before precipitating uranium.

*Determination of Lead in Euxenite, Polycrase, Samarskite,
Etc.*

Take for analysis 4 or 5 grams of powdered mineral. Add five times as much sodium bisulphate, and fuse at bright red until evolution of sulphuric anhydride nearly ceases. Cool, and add an amount of sulphuric acid equal in cubic centimeters to the weight in grams of sodium bisulphate (or a little less). Digest for $1\frac{1}{2}$ hours at heavy fumes of sulphuric anhydride. Cool, and dissolve in cold water, transferring to beaker. Let stand over night. Any precipitate is disregarded.

To the solution plus precipitate, add solid sodium carbonate until about 5 cc. free sulphuric acid is left (as directed under determination of uranium and thorium in euxenite). Make volume 450 cc. and boil vigorously for one-half hour. Let hydrolyzed precipitate of titanium, tantalum, and columbium oxides settle on steam bath, and filter. Wash with hot water. Remove as much as possible of precipitate from filter with platinum spatula, and place in a solution of 50 cc. nitric acid: 150 cc. water. Boil a little, and filter through same filters as before. Keep the sulphuric acid filtrate and the nitric acid filtrate separate.

The precipitate is again removed with spatula from the filters, and placed in platinum crucible. After ignition of the precipitate the filters are placed on top and ignited.

The sulphuric acid filtrate is evaporated to small bulk. If a precipitate forms it is filtered off and ignited with the rest. Also, evaporate the nitric acid filtrate to less bulk, and set both solutions aside for additions.

The ignited precipitates are fused with five times their weight of sodium bisulphate, and the subsequent procedure carried out as before. The filtrates are united with the corresponding ones from first fusion, first neutralizing approximately the sulphuric acid filtrate with sodium carbonate so that only about 5 cc. free sulphuric acid remains in the combined solution. Finally a third fusion and subsequent operations are performed. The final precipitate from hydrolysis, after leaching with nitric acid, is rejected.

In the sulphuric acid solution having about 5 cc. free sulphuric acid in 300-400 cc., hydrogen sulphide is passed to precipitate lead sulphide (in cold to hot to cold solution). Filter. Wash with cold aqueous solution of hydrogen sulphide. The lead sulphide is dissolved in nitric acid, and the solution is added

to the previous nitric acid solution obtained from the digestion of the hydrolysis precipitates. This nitric acid solution now contains all the lead, and traces of other metals. Add to it 3 cc. sulphuric acid and evaporate to fumes of sulphuric anhydride. Take up with a very little water. Warm a little, then cool, and let stand in the cold for 1-2 hours. Filter, and dissolve the lead sulphate in hot ammonium acetate (1 part cold saturated solution of ammonium acetate to 3 parts water). Proceed as given in last two paragraphs of lead in monazite. The procedure is to precipitate lead sulphide with hydrogen sulphide, dissolve in nitric acid, and evaporate in porcelain crucible with 3-4 drops sulphuric acid.

Determination of Thorium in Monazite.

Use a sample of about 6 grams in large crucible or platinum basin. Add about 5 cc. hydrofluoric acid and 15 to 20 cc. sulphuric acid. Heat to rather strong fumes of sulphuric anhydride for about 6 hours, stirring occasionally with platinum spatula. Decomposition should be complete. Take up with water, and make volume 200-250 cc. Let stand until practically all is in solution. Without filtering, neutralize part of the sulphuric acid with solid sodium carbonate, leaving 3-4 cc. free sulphuric acid. Disregard any precipitate if solution is kept distinctly acid. Add the solution, drop by drop, to 200 cc. of a cold saturated solution of oxalic acid containing 10-15 grams excess of the crystals of oxalic acid, stirring repeatedly. Set on steam bath for several hours. Cool and let stand over night.

Filter. Remove final portions of precipitate from beaker with small successive additions of filtrate. Wash with dilute oxalic acid (1 part cold saturated oxalic acid:10 water). Reject filtrate.

Remove from the filter as much as possible of the precipitate with a platinum spatula, and transfer to crucible. Place the filter paper on top, dry, and ignite. Digest again with 15-20 cc. sulphuric acid, as at first, and repeat the process of dissolving and precipitating with oxalic acid. (Before the second precipitation a few cubic centimeters of sulphurous acid is added.)

The second oxalate precipitate is removed from the filter with a spatula, and transferred to a beaker. It is thoroughly dried at a gentle heat, and dissolved in fuming nitric acid. The

filter with a little adhering precipitate is washed with strong nitric acid. The solution is evaporated to dryness, and a little fuming nitric acid added. The resulting solution is united with the main nitric acid solution of thorium and rare earths. Dry on the steam bath until there is a hard cake with no perceptible odor of nitric acid. Take up with 100 cc. of a 20 per cent solution of ammonium nitrate. (It may be found that in evaporating the nitric acid solution on the steam bath, it is very difficult to drive out all nitric acid. In that case drive out as much as practicable, take up with ammonium nitrate solution, and add dilute ammonia until there is a little permanent precipitate. Then proceed with the peroxide precipitation as below. In the subsequent repetitions, prescribed below, no difficulty will be found in expelling all nitric acid.)

Bring the solution to a boil, withdraw heat, and add 5 cc. perhydrol (30 per cent peroxide of hydrogen) in a little water. Let stand a few minutes, filter, and wash with hot two per cent ammonium nitrate. Dissolve precipitate in hot dilute nitric acid, and dry again on steam bath. Make a second and then a third precipitation of peroxynitrate of thorium. The first precipitate will probably be buff from contaminating cerium, and the second cream-colored; the third should be white. Wash the third with hot two per cent ammonium chloride, dissolve in 10 cc. hydrochloric acid, and make volume 450 cc. Add 5 cc. sulphurous acid, bring to a boil, and run in slowly with a pipette 35 cc. of a solution of oxalic acid containing 60 grams per liter. Boil 15-20 minutes, taking care to avoid bumping. Set on steam bath 3-5 hours, and then let stand in the cold over night. Filter, and wash with weak acidulated water (1 drop hydrochloric acid:100 cc. water). Ignite strongly, and weigh as ThO_2 .

The precipitation of thorium with hydrogen peroxide is apparently sensitive to changes of conditions, and the method has been thought by some workers to be unreliable. There seems to be some basis for this view, as I have found that unless certain requirements are fulfilled hydrogen peroxide will fail to precipitate some or even a large part of the thorium, but under proper conditions recovery seems to be complete. Necessary or desirable conditions are the following:

A preliminary precipitation of thorium and rare earths with oxalic acid, followed by complete drying of the precipitate, and conversion into nitrates with fuming nitric acid.

A neutral or only very slightly acid solution of the nitrates when the peroxide precipitation is made, and the presence of a strong electrolyte.

Repeated precipitations with peroxide to get rid of cerium. In spite of statements found in some text-books, one precipitation is not sufficient if much cerium is present.

In order to test the accuracy of the above-described oxalic acid-hydrogen peroxide procedure for recovering ThO_2 , the following experimental run was carried out.

A sample of thorium nitrate from J. T. Baker Chemical Co. was used as the source of ThO_2 . A weight of 0.5225 gram of nitrate was taken, and this was ignited, gently at first, and finally for 15 minutes over a large Meker burner. The residue of ThO_2 weighed 0.2453 gram.

To it was added about 1.52 grams of a mixture of rare earth oxides from which all thorium had been extracted in previous analyses.

Fused with 20 grams of sodium bisulphate at bright red, and digested with 20 cc. hot (boiling) sulphuric acid. Took up with 450 cc. water, and set on steam bath for one hour. Considerable material was left undissolved. Poured off solution and nearly neutralized it with sodium carbonate. Boiled 20 minutes to expel carbon dioxide. Poured solution back on undissolved salt, and added the solution, by drops, to 200 cc. of a cold saturated solution of oxalic acid containing about 18 grams excess of crystalline oxalic acid. (This quantity of oxalic acid was more than necessary, as some was left undissolved in cold solution.) Heated on steam bath for about two hours. Set aside over Sunday (about 40 hours). Filtered. Washed precipitate from filters into beaker, and treated filters (laid unfolded against inside of another beaker) with strong nitric acid. Evaporated solutions to dryness, and heated in oven for short time at 120-130°. Added fuming nitric acid, and evaporated on steam bath to a slightly moist salt. Dissolved in 300 cc. hot water, and in order to test the completeness of the decomposition of the oxalates the solution was boiled vigorously 23 minutes and set aside over night. No precipitate appeared.

Heated solution nearly to boiling and added ammonia until there was a little permanent precipitate, then added 10 grams ammonium nitrate, and heated again to boiling. Withdrew heat, and immediately added 7 cc. perhydrol in a little water. Considerable quantity of buff precipitate. Let settle, and

filtered. Washed with hot two per cent ammonium nitrate. Filtrate pale lilac; rejected. Dissolved precipitate in hot strong nitric acid, and evaporated on steam bath to a pale yellow crust with little or no odor of nitric acid. Took up with 100 cc. of two per cent ammonium nitrate. Repeated precipitation with perhydrol, and made still a third precipitation. The third precipitate was light cream-colored. Washed with hot two per cent ammonium chloride.

Dissolved the third perhydrol precipitate in 10 cc. hydrochloric acid, and added 5 cc. sulphurous acid. Diluted to 450 cc., and precipitated with 35 cc. of stock solution of oxalic acid, containing 60 grams per liter. Boiled 35 minutes and set on steam bath. Kept hot 3 hours, 20 minutes, and set aside over night. Filtered, and washed with acidulated water (1 drop hydrochloric acid per 100 cc.). Ignited precipitate strongly and weighed. Weight = 0.2451 gram.

The ThO_2 was so nearly white that its pale pink color was almost imperceptible. The results indicate that the method is satisfactory when carried out as described. In actual analyses also consistent and apparently reliable results have been obtained.

Determination of Uranium in Monazite.

There is a question whether fresh monazite carries uranium. The small amounts sometimes found may have migrated in along veinlets of alteration, having been derived from adjacent uranium minerals. However, it may be desirable to determine whether it is present, and its amount. The following procedure, based on that of Fresenius and Hintz, seems to give good results. It depends upon the ability of potassium ferrocyanide to precipitate uranium in a slightly acid solution.

Take 5 grams powdered mineral.

Decompose it with hydrofluoric and sulphuric acids as given under thorium in monazite. Take up with water and make volume about 250 cc. Add crystalline potassium carbonate until most of the sulphuric acid is neutralized. The greater part of the rare earths is precipitated as double sulphates. Warm and filter, and wash with hot strong solution of potassium sulphate. Reject precipitate. Boil filtrate until carbon dioxide is expelled and add ammonia in small excess. Filter, and wash with hot two per cent ammonium nitrate solution. Reject filtrate. Wash precipitate into platinum basin, and treat precipitate and papers with weak hydrofluoric acid.

Evaporate to small volume, filter off the precipitate of fluorides of thorium and rare earths, and wash with warm dilute hydrofluoric acid. Reject precipitate. To filtrate add 3-5 cc. sulphuric acid, and evaporate to heavy fumes. Take up with water and heat, then cool. Make volume about 150 cc. and add excess of potassium ferrocyanide solution and saturate with sodium chloride. Let stand several hours, filter, and wash with strong solution of sodium chloride. Digest precipitate (of ferrocyanides of uranium and iron) with cold dilute sodium hydroxide or potassium hydroxide until all the ferrocyanide precipitate is converted to hydroxide. Wash with two per cent ammonium chloride plus a little ammonia until no ferrocyanide solution is left.

Dissolve precipitate in hydrochloric acid. Make volume about 300 cc., neutralize with sodium carbonate, and add about two grams excess of the crystals. Boil, and filter; wash with hot two per cent ammonium nitrate. Reject precipitate. Acidify filtrate with hydrochloric acid, and boil out carbon dioxide. Add ammonia in excess, and boil. Filter, and reject filtrate. Dissolve precipitate in a little nitric acid, add ammonia in excess, and then an ammoniacal solution of ammonium carbonate, as described in the last portion of the determination of uranium in euxenite. Continue as there given.

Determination of Lead in Monasite.

Use 20-30 gram sample in large platinum basin.

Add 5-10 cc. hydrofluoric acid and 50-60 cc. sulphuric acid.

Heat to rather strong fumes of sulphuric anhydride for about six hours, stirring occasionally with platinum spatula. Cool. Transfer to beaker and add water to about 175 cc., and 300-350 cc. alcohol. Stir, and let stand one to two hours; then filter with decantation. Wash precipitate left in beaker 3-4 times with pure alcohol, stirring up and allowing to settle each time, and filtering. The lead is retained as sulphate, insoluble in alcohol.

The small amount of precipitate on filter is washed with alcohol, and all alcoholic filtrates rejected. The precipitate on filter is then leached with cold water, and filtrate set aside to be used for dissolving main precipitate after drying. The precipitate on filter is then leached with hot dilute nitric acid, and this filtrate also set aside for additions. The filter paper with its small residue is rejected.

The main precipitate in beaker, after its washing with alcohol, is dried in oven, at first at about 70° , and afterward for a short time at $130-150^{\circ}$. Dissolve it in cold water and add the aqueous extract from leaching. Make volume about 350 cc. and add 5 cc. sulphuric acid. Practically all except lead sulphate should dissolve. Filter, and wash with cold water. The residue on filter is dissolved in hot dilute nitric acid, and added to previous nitric acid leaching solution.

In the filtrate, now about 450 cc., which may contain a little lead sulphate, pass hydrogen sulphide (in cold to hot to cold solution). On heating, a small amount of sulphates of rare earths will probably be precipitated with the lead sulphide, but this precipitate is disregarded. Filter, and wash with cold water + hydrogen sulphide. Reject filtrate. Dissolve precipitate in hot dilute nitric acid, and unite with previous nitric acid extracts. To united solutions add 8 to 10 cc. sulphuric acid, and evaporate to fumes of sulphuric anhydride until all nitric acid is expelled. Cool, and add water, keeping volume not more than 50-75 cc. Heat a little to dissolve all but lead sulphate. Cool and let stand 1-2 hours and filter. Wash with a little cold water containing 30 cc. sulphuric acid per liter. Reject filtrate. Dissolve the lead sulphate in strong hot ammonium acetate (one part cold saturated solution of ammonium acetate to three water). Let stand over night. There may be a little white flocculent precipitate formed. Filter off and reject.

In the ammonium acetate solution of lead sulphate (diluted) pass hydrogen sulphide (in cold to hot to cold solution). Filter, and wash with cold water + hydrogen sulphide. Reject filtrate. Dissolve precipitate in a little warm dilute nitric acid. Evaporate to dryness in weighed porcelain crucible with 3-4 drops sulphuric acid.² If solution blackens near end of evaporation, destroy organic matter with a few drops of fuming nitric acid. Finally ignite at low red, and weigh as $PbSO_4$.

The lead sulphate should be white. If tinged with color, dissolve in warm solution of ammonium acetate, filter, and ignite and weigh the residue. Subtract from the lead sulphate.

² The distilled water and the nitric acid used in the final operations must be above suspicion with respect to soluble salts, otherwise the weight of lead sulphate will be too high.

SUMMARY:

For calculations of geologic age from the content of uranium, thorium, and lead in a mineral, a correct analysis is a fundamental requisite, but the minerals in which these elements occur are often of such composition as to present special difficulty to the analyst.

In this paper detailed descriptions of methods of analysis are given, which have been found in practice to work well and to give apparently reliable results. They are offered for the consideration of analysts who have had experience with similar material.

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RADIOACTIVE MINERALS FROM DIVINO DE UBÁ, BRAZIL.

CLARENCE N. FENNER.

The discovery within recent years that the elements uranium and thorium are constantly undergoing atomic disintegration, by which a series of other elements is formed, with lead as an end-product, promises to be of the greatest service to geologists in establishing absolute figures of geologic age.

The principle on which calculations are based is simple; it is only necessary to determine by analysis of a mineral the amounts of uranium and thorium present, and of the lead derived from them, and to calculate by the appropriate formula the length of time required to produce this amount of lead. In application, however, difficulties and uncertainties arise. It has been found, for instance, that while analyses of minerals in which the parent element is chiefly uranium have given results which, on the whole, appear fairly reasonable and consistent, those in which thorium plays a similar part are likely to give figures which are not consistent among themselves or with those derived from uranium.

Several explanations or qualifying assumptions of more or less probability have been suggested, among them that isotopes of uranium and thorium have existed which have disintegrated at a different and unknown rate, or that the final product of thorium is not lead but some other element. Of a different sort is the suggestion that by metamorphic processes or by weathering, or by some process in which circulating solutions have been active, the lead formed by radioactive disintegration has not remained in place in its proper relative amount, but that some has been leached out or some introduced from adjacent sources, and that thorium minerals have been especially affected. There is also a possibility that lead not of radioactive origin was deposited at the time of original formation of the mineral; or that the experimental determination of the fundamental constants of disintegration is somewhat in error; or finally, that because of the difficulties involved in the analytical determination of these elements incorrect results have been reported.

About two years ago Mr. Frank L. Hess, of the U. S. Bureau of Mines, received a large sample of minerals from Divino de Ubá, Minas Gerães, Brazil, sent by Dr. Djalma Guimarães. From the general appearance and properties of

the minerals Mr. Hess classified them as samarskite, monazite, and columbite. Many of the pieces were large single crystals. The samarskite and columbite were very little weathered; the monazite was somewhat more altered, but many pieces could be picked out which were fairly fresh. The occurrence of samarskite, essentially a tantalate and columbate of uranium and other bases with but little thorium, and of monazite, a phosphate of thorium and rare earths, with little or no uranium, in a single deposit, gave an unusual opportunity to obtain information on some of the questions that have been raised. Calculations of age based on the content of uranium, thorium, and lead in the two should give nearly the same result for each, if the fundamental theory is correct and if sources of error are eliminated.

The following brief description of the field occurrence is taken from the translation of a longer article by Dr. Guimarães, published in the *Serviço Geológico e Mineralógico do Brasil*, Bulletin No. 13, 1925:

The deposit is situated about one kilometer southeast of Divino field, in the town of Ubá, State of Minas Gerães. One mile south of Divino are hills capped with quartzite, interstratified with mica schist, in layers slightly inclined toward the east. These are regarded as possibly of Algonkian age. The minerals occur in a vein of pegmatite running approximately in a north-south direction in a hill the soil of which is composed of a layer of ferruginous clay, 1 to 2 meters thick or more. It was not possible to obtain fresh specimens of the rocks immediately adjacent to the vein. The width of the vein of pegmatite may be estimated at 6 meters. Prospecting disclosed a great mass of quartz (almost 2 meters thick) of lenticular form and vertical position, at the sides of which were found distributed in the kaolinic mass "books" of mica, in connection with which crystalline masses of samarskite, columbite, and monazite occur. The habitual association of the three minerals is in aggregated radiation, in which columbite predominates. Generally the center of radiation of the minerals consists of samarskite, which is often in crystallographic continuity with columbite. Some specimens of columbite, on being broken open, show an interior of samarskite. The monazite occurs in large crystals.

Data on crystal form are also given by Dr. Guimarães. In a later bulletin (No. 18 of the same Service; 1926) Dr. Euzebio de Oliveira gives further information on radioactive minerals of Brazil, and quotes an analysis of samarskite from

Divino de Ubá, made by Dr. Guimarães. The figures given for uranium, thorium, and lead differ considerably from those of the present article. It seems probable that part, at least, of

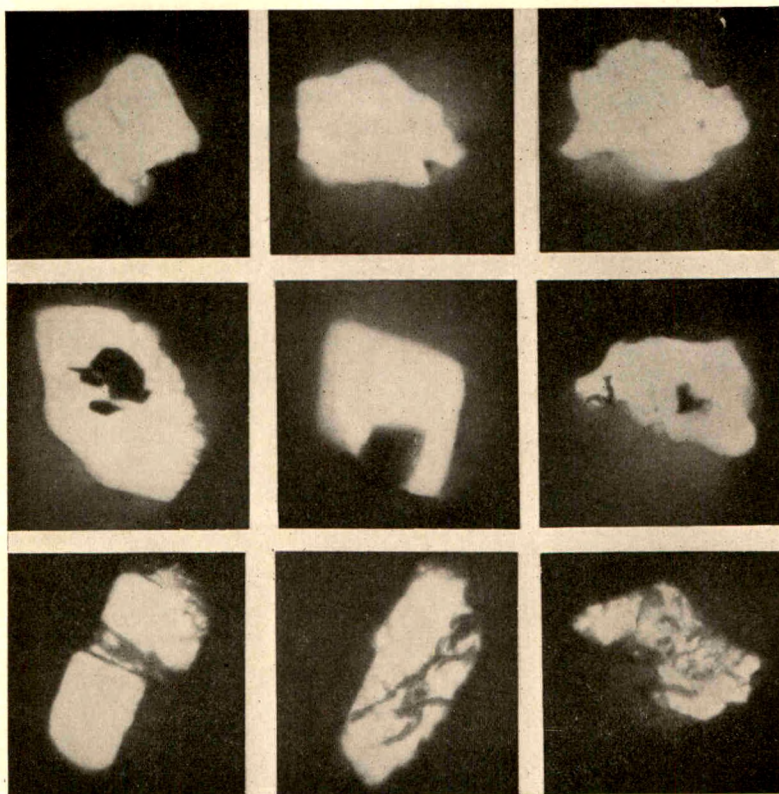


Fig. 1. Auto-radiographs of samarskite from Divino de Ubá. The specimens were polished on one side, and laid face down on transparent celluloid, about 8/1000 inch thick, covering a photographic film, and left for 72 hours.

The three uppermost show nearly homogeneous samarskite, the next three have inclusions of columbite, and the lowest three are cut by veins of decomposition products.

Taken by Frank L. Hess.

the differences may be attributed to the special methods employed in the present investigation to get rid of decomposition products of altered composition, as will be more fully described.

Although the minerals in the sample received by Mr. Hess were fairly fresh in appearance, there was evidence of some decomposition, especially of the monazite. If this alteration had effected considerable change in the relative amounts of lead, uranium, and thorium in the weathered products, the inclusion of even a small amount of decomposed material in the analyzed samples would lead to incorrect results. It was desirable, therefore, to obtain information on this matter, and also to endeavor to devise means by which the samples for analysis should be freed of alteration products.

Treatment and analysis of the monazite. The least altered portions of the monazite were semi-transparent, and of a light brownish-yellow color; the luster was resinous, inclining toward vitreous or adamantine. Alteration had produced a dull, earthy material of brownish-white color, which covered surfaces and penetrated along cleavage planes and small cracks.

The best-looking pieces were picked out, and were crushed without sifting, so that the largest pieces were $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter and most was a powder. This material was placed in cold dilute nitric acid (1 part acid to 3 parts water), and allowed to soak for about 48 hours, with occasional shaking. The acid solution was poured off, and set aside for investigation. The mineral powder was washed several times with water, and then allowed to soak in water for about 12 hours, and finally dried at 110° .

This treatment with weak nitric acid seemed the best that could be devised for leaching from the decomposition products the lead and thorium, in whatever proportions they might occur, without much action upon the monazite itself. If the monazite should be slightly attacked, it seemed reasonable that the action of such a reagent as nitric acid would not be selective. These assumptions are based on the general properties of the materials dealt with, but may not be wholly warranted.

The dried monazite was crushed to pass a sieve of 100 meshes per inch, and was then sifted on a 220 mesh bolting-cloth. The portion that passed through weighed 154 grams, and was rejected; the portion retained weighed 187 grams, and was used for analysis. This treatment was based on the view that the altered material was more friable and would be reduced to smaller dimensions in crushing. The portion used for analysis, when examined microscopically, still showed a little turbidity in some grains, but the appearance was much better than that of the powder of less than 220 mesh.

Analytical methods have been described in detail in another article, and will not be considered here.¹ Multiplicate analyses were made in order to furnish checks and to reduce the probable average error. Only the elements involved in age-calculation were determined. The amount of lead present was found to be so small that errors of the magnitude usually allowable in analytical work would represent a large percentage error, and could hardly be tolerated. In most cases lead was determined on 30-gram samples, and great care in manipulation was used. For thorium the samples ranged from 6 to 30 grams. Results were as follows:

Monazite from Divino de Ubá.		
	ThO ₂	PbO
	5.78%	0.1119%
	5.68	0.1008
	5.78	0.0871
	5.93	0.0909
	...	0.1087
Average ...	5.792%	0.0999%
Th = 5.091%	Pb = 0.0927%	

There is some uncertainty about the equivalence ratio of thorium to uranium in radioactive disintegration, but accepting the factor 0.38 as most probable,² we have for this mineral

$$\frac{\text{Lead}}{0.38 \text{ Thorium}} = 0.048.$$

The factor to be used for the transformation of uranium into lead (the disintegration constant of uranium) is also somewhat in doubt. The fundamental formula for calculating ages is

$$t = \frac{\log U_0 - \log U_t}{\lambda \times 0.434}$$

in which t = elapsed time (age of mineral)

U_0 = original uranium = uranium now present + (lead $\times$ 1.156)
+ (uranium equivalent of thorium)

U_t = present uranium + uranium equivalent of thorium

λ = disintegration constant of uranium.

The International Critical Tables, using for λ the value 1.50×10^{-11} years, give the formula

¹ Preceding article on Analytical Determination of Uranium, Thorium, and Lead as a Basis for Age-calculations.

² In the International Critical Tables of the National Research Council (1926), the factor 0.28 is given on p. 381, vol. 1. This is evidently a misprint. At the top of p. 382, 0.38 is given.

$$\text{Age} = \frac{\log(U + 0.38 \text{ Th} + 1.156 \text{ Pb}) - \log(U + 0.38 \text{ Th})}{6.5 \times 10^{-8}}$$

million years.

Ellsworth³ adopts the value of $\lambda = 1.392 \times 10^{-11}$, which causes the figure 6.5 in the denominator of the last equation to be replaced by 6.04.

Holmes and Lawson⁴ believe a more nearly correct value of λ to be 1.57×10^{-11} , and recast the formula into a rapidly converging series

$$\text{Age} = \left(\frac{\text{Pb}}{U + 0.38 \text{ Th}} \times 7400 \right) \left(1 - x + \frac{x^2}{2} + \frac{x^3}{3} \right)$$

in which $x = 1.155 \times \frac{\text{Pb}}{U + 0.38 \text{ Th}}$.

In the present paper the formula and numerical factors of the International Critical Tables will be used.

Calculation with the above formula gives

$$\text{Age} = 360,000,000 \text{ years.}$$

In recorded analyses of monazite uranium is seldom mentioned, and is probably seldom looked for. In this sample U_3O_8 was found to amount to 0.06 per cent (determined on a 5 gram sample). There is a question whether this uranium is properly a constituent of the original monazite or whether it was brought in by circulating waters from adjacent uranium minerals. Mr. Hess has informed me that commercial companies, in working up large quantities of monazite, find indications that similar amounts of uranium are generally present, but here again the same query arises. If, however, the amount found in the Brazilian monazite is used in calculation of age we obtain 351 million years.

The nitric acid solution used in leaching the mineral was found to contain

$$\text{PbO} = 0.0421 \text{ gram} \qquad \text{ThO}_2 = 1.6076 \text{ grams}$$

This had been leached from approximately 341 grams of mineral, and therefore, in terms of the mineral, it amounted to

PbO	0.0123 per cent	ThO ₂	0.471 per cent
or Pb	0.0114 per cent	Th	0.414 per cent

The ratio of lead to (thorium $\times 0.38$) in the leaching solution comes to 0.072, compared with 0.048 in the portion of the

³Ellsworth, H. V., Radioactive minerals as geological age indicators, this Journal, 9, 133, 1925.

⁴Holmes, Arthur, and Lawson, Robert W., Factors involved in the calculation of the ages of radioactive minerals, this Journal, 13, 327, 1927.

leached mineral taken for analysis. The difference in ratios is large, but the amounts of lead and thorium leached out per gram of mineral are so small that they are not of great significance when applied to calculations of age. For instance, if we make the rather extreme assumption that the amount leached out per gram was the same for the fresh-looking portion of mineral retained on the 220 mesh bolting-cloth as for the portion that passed through (which included the greater part of the friable, decomposed material), and recalculate the age on this assumption we have

$$\begin{aligned}\text{ThO}_2 &= 5.792 + 0.471 = 6.263\% \\ \text{PbO} &= 0.0999 + 0.0123 = 0.1122\%\end{aligned}$$

and the age equals 373,000,000 years. This is not widely different from the 360,000,000 years previously found. The conclusion indicated for this sample is that, while it may have been worth while to leach the mineral in order to remove lead and thorium from decomposition products, the magnitude of the figures for age is not greatly changed. The separation of the mineral powder into two portions by sifting on the 220 mesh bolting-cloth may well have been a much more effective means of getting rid of decomposed material of changed lead-thorium ratio, but no actual figures on this point have been obtained.

Treatment and analysis of the samarskite. The best-looking pieces were selected. Even these showed occasional veinlets of alteration penetrating the interior, and they had an outside skin of yellowish or light brown decomposed material. The fresh portions were dark brown, almost black, in color, had a conchoidal fracture, and brilliant resinous luster. Fresh fractures closely resembled freshly broken tar.

Two sets of analyses of this mineral were made, with material treated in different ways. With the first, unbroken lumps of large size were soaked for 19 hours in 1 part nitric acid to 10 parts water, and the surficial crust was scraped off with a sharpened file. Analysis of a 2 gram sample gave

Samarskite from Divino de Ubá.

	$\text{U}_3\text{O}_8 = 12.83\%$	$\text{ThO}_2 = 1.87\%$	$\text{PbO} = 0.56\%$
or	$\text{U} = 10.88\%$	$\text{Th} = 1.64\%$	$\text{Pb} = 0.52\%$
	Pb		
	$\frac{\text{U} + 0.38 \text{ Th}}{\text{U} + 0.38 \text{ Th}} = 0.045.$		

Age = 340,000,000 years.

For the second set of analyses a more thorough preliminary treatment was given. As with monazite, the specimens were

broken up so that the largest pieces were $\frac{1}{4}$ to $\frac{1}{8}$ inch in diameter, and most was a powder. This was placed in a cold solution of 1 part nitric acid to 3 parts water, and allowed to soak for 65 hours. It was then washed and dried, crushed to pass 100 mesh, and sifted on 220 mesh bolting-cloth. The portion retained weighed 58 grams, and was used for analysis; the portion that passed through weighed 51 grams, and was rejected. Three-gram samples were used for analysis. The results were

Samarskite from Divino de Ubá.

	U ₃ O ₈	ThO ₂	PbO
	11.53%	1.706%	0.596%
	11.55	1.647	0.574
	11.40		
Average	11.493%	1.676%	0.585%
	U = 9.746%	Th = 1.473%	Pb = 0.543%
	Pb		
	U + 0.38 Th = 0.053		
	Age = 395,000,000 years.		

After these results were obtained, further tests of the action of dilute nitric acid upon the samarskite were made. A portion of the specially treated sample used for analysis was ground in an agate mortar until an almost impalpable powder was obtained. Two grams of this was placed in a beaker, and 10 cc. nitric acid: 30 cc. water added. It was allowed to soak, with occasional stirring, for 46½ hours. The leaching solution was poured off, filtered, and its content of uranium and lead determined.* The results were:

U ₃ O ₈ = 0.13%	PbO = 0.06%
U = 0.11%	Pb = 0.055%

These amounts are small, but are rather larger than was expected to be obtained by the action of dilute nitric acid upon the mineral, and the ratio of lead to uranium is also unexpectedly large. It would be gratifying to be able to interpret their meaning with confidence, but we can only reason upon them in a general way.

There are two contrasted explanations, either one of which may be partly correct. We may suppose, in one case, that only unaltered samarskite was present, and that the nitric acid dis-

* Thorium was not determined. At the point of the analysis where total thorium and rare earths would be precipitated by hydrofluoric acid, there was not more than a trace of precipitate at most. Also, in this mineral the effect of thorium in age computations is small compared with uranium.

solved part of this; in the other case, we may suppose that there were veinlets of alteration products which were opened up to more ready attack of the acid by the fine grinding, and that it was from these that the uranium and lead were extracted.

Unaltered samarskite is regarded as so resistant to attack by even hot concentrated sulphuric acid, that a bisulphate fusion is generally resorted to in analytical work, but if it was attacked by the dilute nitric acid, there is still a question whether the analytical figures first obtained should be corrected by adding to them these latter figures, in order to correct for the first treatment with acid. This would increase the age to 429,000,000 years, but even under such an explanation of derivation of lead and uranium in the acid solution probably no such correction should be made. At the time of the first nitric acid treatment the mineral was in much coarser grains and thus exposed much less surface. Moreover, it underwent a subsequent grinding, by the attrition of which the surfaces acted upon by acid would tend to be ground off, and all the finest material was separated by sifting, and rejected.

The second possible explanation, that the small amounts of uranium and lead found in the acid came from veinlets of alteration, is supported to some degree by the different ratio of lead to uranium from that in the main sample; also, examination with a binocular shows that small veins of altered material do penetrate deeply into specimens. In order to obtain more information on this and other matters Mr. Hess kindly made a large number of auto-radiographs of different specimens of samarskite. Typical examples are shown in the accompanying illustration. From these it is evident that while some specimens are perfectly homogeneous, many others are cut by veins of alteration products. It seems as if these veins might well be the source of the uranium and lead leached out of the finely ground material. Under this supposition the correction is to be subtracted from the original figures, and an age of 360,000,000 years is obtained.

This last figure is precisely that calculated from the monazite analyses that are believed to be most reliable, but to some degree this coincidence is unquestionably due to a balancing of errors. As has been pointed out in the course of the article, after getting rid of major sources of error there are still several uncertainties left which, though probably small, forbid a statement that any one figure should be accepted as the exact value.

The investigation has shown rather definitely that even the most favorable-appearing minerals should be carefully scrutinized and tested, and decomposed or altered material removed, before proceeding with analyses; otherwise analytical results may indicate ages quite different from the true figures.

Though there are still uncertainties connected with the ages found in the present investigation, they are probably not of large amount, and it is gratifying to find that under almost any reasonable assumption that may be made, the age indicated by the monazite is very close to that indicated by the samarskite, and such differences as there are may be accounted for without having recourse to hypotheses outside of the straightforward theory of atomic disintegration that is usually accepted.

SUMMARY.

In a collection of radioactive minerals from Brazil specimens of monazite, a thorium mineral containing little uranium, and of samarskite, a uranium mineral nearly free from thorium, were subjected to a preliminary treatment to remove decomposition products, and were then analyzed for uranium, thorium, and lead as a basis for calculations of age. With both minerals the results indicate an age of about 360,000,000 years. This is believed to be close to the correct figure, but there are uncertainties due to various causes, and especially to some question as to whether the preliminary treatment had completely removed decomposition products. These matters are discussed, and emphasis is laid on the importance in all work of this kind of seeing that decomposition products be removed as completely as is practicable. It is believed that unless careful attention is paid to this matter misleading results are likely to be obtained.

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THE FLOATING NEEDLE EXPERIMENT.

FREDERICK E. BEACH.

Abstract

On account of certain dubious but widely published accounts of the way in which a needle is supported at the surface of water, a method was devised to increase the scale of the experiment and subject the different factors which contribute to the support of the floating body to quantitative determination. It is shown that a needle floating at the surface of clean water does not lie in the hollow of a membrane of any toughness but that the film is attached to the needle at a definite angle of contact and that the presence of oil has an adverse effect upon the support of the needle.

Having demonstrated that the contact angle of water against an aluminum surface is virtually the same as that against steel, the author constructed a hollow aluminum torus which was used as the floating body since this symmetrical form exhibits greater stability on the surface of water than a spindle-shaped needle. The three factors which contribute to the support of the body are (a) the buoyancy due to the liquid displaced by the portion of the body immersed in the water; (b) the buoyancy due to the weight of the liquid which has been removed from the space vertically over the bared portion of the ring, and (c) the upward components of the surface tension. These three effects were computed from the experimental data and their sum found to be equal to the weight of the body, at least to the degree authorized by the errors of observation. The upward pull of surface tension was also shown to be equal to the weight of water which would just fill the space over the depressed liquid surface up to the undisturbed horizontal level, whence it follows that the weight of any floating body is equal to the total volume of the liquid displaced by the body below the upper horizontal level without regard to the form assumed by the surface, or the value of the surface tension. A further experiment was carried out with a dusted surface in which the ring lay in the hollow of a film which did not wet the metal at all. In this case also the observed and computed values of the supporting factors were found to be in satisfactory accord.

I. Practically all of the writers from Deschanel to Sheldon, who mention the possibility of floating a needle at the surface of water, describe it as resting in a hollow trough in a sagging surface as if it lay upon an elastic skin of definite toughness. It is surprising that none of the authors have observed that the real configuration at the needle is that of Fig. 1. In order that the needle should lie in a trough as in Fig. 2 it is requisite that there be no adhesion at all of the water to the steel. In other words, the angle of contact of water against steel should be 180° . These assumptions are demonstrably untrue. A needle touched to the surface of water and then raised shows considerable attachment between it and the water. A small drop of water placed upon a clean polished knife blade assumes a hemispherical form exhibiting an angle of contact approaching a right angle. Its value according to the writer's measurements was about 86° .

Another assertion frequently made is that the flotation of the needle is assisted by oiling it slightly. This also is not in accord with the writer's experiments. Measurements on a drop of water on steel which had been slightly oiled with oleic acid showed an angle of contact between 30° and 40° , i.e., a reduction of at least 50 per cent.

The tapered form of a sewing needle is a poor one to try to float. It exhibits a tendency to plunge on account of the asymmetry of the ends. As compared to the needle a ring 5 cm. in diameter made from a steel wire of a millimeter cross-section was found to be more stable for the experiment. No particular difficulty was encountered in floating such a ring provided it was thoroughly clean, but it was found almost impossible to get it to float when it had been rubbed through the fingers after they had been moistened with oil.

A third assertion, namely, that the weight of the needle is equivalent to the weight of the liquid which would occupy the whole of the depression due to the needle, seems possibly open to question in view of the upward component of the force contributed by the film where it is attached to the body. At least, several of my colleagues who examined the phenomenon were of this opinion, for certainly Archimedes' principle as usually demonstrated does not take account of surface forces. It accordingly seemed desirable to increase the scale of the apparatus and submit the matter to quantitative test.

II. As a preliminary examination of drops of water upon a polished aluminum plate showed that the angle of contact

scarcely differed from that against steel, a tube of aluminum about 6 mm. in diameter was selected and formed into a closed ring, or torus, of approximately 6 cm. outside diameter. Its weight at that time was 7.13 gms. When carefully cleaned there was no difficulty in floating it. The water surface met the cross-section as in Fig. 1 with an angle of contact of 85° as judged from drops on a flat aluminum plate. A small basket was suspended from the lower side of the ring so as to hang under water and receive additional weights. When the clean ring was floating with the submerged basket, small shot were introduced into it until the ring was just dragged under. The basket and its contents were then weighed under water and it was found that it had taken an additional force of 2.17 gms. to pull the ring under. The ring was next rubbed with oleic acid, but it alone, i.e. without the basket, could not be made to float. The angle of contact on a similarly oiled aluminum plate was about 40° . When rubbed with crude oil the torus was successfully floated but it remained on top for less than a minute. Rubbed with creosote the flotation continued for a limited time not noted. The contact angle for this case was about 69° .

These results are what would have been expected from the knowledge that the presence of oil diminishes both the surface tension and the angle of contact.

To find how far the observed position of the ring when floating meets the requirements of theory the following notation referring to Fig. 1 may be adopted:

- D = mean diameter of torus.
- m = mass of torus.
- r = radius of tube, or cross-section of the torus.
- h = LE, height of free surface above point of contact B.
- θ = angular distance of B from the vertical.
- ω = angle the liquid surface makes with horizontal at B.
- α = angle of contact.
- ρ = density of the liquid.
- S = surface tension.
- l = LT, distance of top of ring below the level surface.
- a = TE, distance of top of ring above B.

The condition that the ring should float is

$$2\pi DS \sin \omega + 2\pi Drh\rho g \sin \theta + \pi Dr^2 (\pi + \frac{1}{2} \sin 2\theta - \theta) \rho g = mg \quad (\text{eq. 1})$$

The first term gives the upward pull of the surface; the second is the buoyancy due to the exposed area AB at the depth h,

that is the weight of the liquid which would fill the space AEBB'A', and the third term accounts for the liquid displaced by the portion AGB of the torus immersed.

The equation for the contour of the liquid surface will also be useful. It must satisfy the condition that the change of pressure in passing from the convex to the concave side is equal to the product of the surface tension and the curvature, that is, approximately

$$y\rho g = \frac{S}{R} \quad (\text{eq. 2})$$

where y is the distance of any point of the contour line below the horizontal and R is the radius of curvature in the vertical

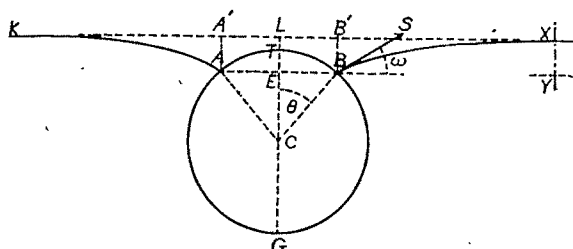


Fig. 1.

plane. The curvature of the surface in the other normal plane at right angles to this has been neglected as probably not coming within the range of the experimental measurements. Introducing the slope of the tangent

$$\frac{dy}{dx} = \tan \phi \text{ and } R = \frac{\left\{ 1 + \left(\frac{dy}{dx} \right)^2 \right\}^{\frac{3}{2}}}{\frac{d^2y}{dx^2}}$$

we obtain by integration

$$\frac{y^2 \rho g}{2} + S \cos \phi = S$$

This might have been obtained as

$$\frac{h^2 \rho g}{2} + S \cos \omega = S \quad (\text{eq. 3})$$

for the point B, directly, by considering a section XY in equilibrium under a pressure to the right and the horizontal forces in the levels X and Y.

The primary but least accurate measurement was l , the distance of the top of the ring below the horizontal level. Difficulties in its determination to the order of hundredths of a millimeter arise from the departures of the ring from perfect geometric symmetry and level balance, and also a slow creep of the liquid. The other critical measure is the position of the level AB which may be found either by measuring GE or the length AB . Actually the mean of both determinations was used; h was found from l and a , θ from a and r , and ω from eq. 3.

The directly observed quantities were

$$\begin{aligned} l &= 0.055 \pm .011 \text{ cm.} \\ GE &= 0.521 \text{ cm.} \\ D &= 5.57 \text{ cm.} \\ m &= 7.085 \text{ gm.} \\ m' &= 1.842 \text{ gm. weighed in water,} \end{aligned}$$

and from them were deduced

$$\begin{aligned} r &= 0.309 \text{ cm.} \\ h &= 0.152 \text{ cm.} \\ a &= 0.097 \text{ cm.} \\ \theta &= 46^\circ.7 \\ \omega &= 33^\circ.0. \end{aligned}$$

The angle of contact α , or $\theta + \omega$, equals $79^\circ.7$ which seems reasonable.

S was assumed as 70 dynes per cm. for room temperature. The above values substituted in eq. 1 showed that the surface tension supported 1.360 gm. The buoyant force due to the water displaced from the space vertically over AB was 1.196 gm. and that due to the water displaced by the immersed portion of the torus was 4.720 gm. The total amounts to 7.276 gm. or an excess of $2\frac{1}{2}$ per cent over the weight of the body, but this amount is not greater than the inaccuracy of the smaller quantities involved.

III. To determine the volume of the space $BB'X$, Fig. 1, consider first the case where the contour XB represents the surface film curving down to meet a vertical plane at an angle ϕ with the horizontal. For this case eq. 2 is exact and the differential expression for the area, or the volume per unit length perpendicular to the paper, is readily integrated.

We have

$$y \, dy = y \, dx \tan \phi = \frac{S}{\rho g} \sin \phi \, d\phi$$

or

$$y \, dx = \frac{S}{\rho g} \cos \phi \, d\phi$$

Integrating

$$\int_{y=0}^{y=h} y \, dx = \frac{S}{\rho g} \sin \omega \quad (\text{eq. 4})$$

Multiplying each side by ρg it is seen that the expression on the left is the weight of a block of the liquid a centimeter long and the right hand side is the vertical component of the surface tension. The meaning is that if the space BB'X were filled with the liquid and the surface BX were annihilated the pressure at B would remain unaltered.

If the figure were turned upside down it would represent the case where a liquid rises to meet a vertical plane which it wets, and eq. 4 simply states that the surface tension supports the amount of liquid above the horizontal plane. But this principle is of universal application and will be true for the surface which is formed when a small vertical cylinder is dipped into water or for more complicated surfaces of double curvature assumed by liquids, such as that made by the floating ring. The proof is now complete that the weight of the liquid which would fill the space KAGBX is equal to the weight of the torus.

IV. A modification of the experiment was now made by carefully dusting the surface of the water with lycopodium powder, when it was found that the torus could be supported as in Fig. 2 without the slightest wetting of the metal.

For this case the equation of equilibrium is

$$2\pi DS \sin \theta + 2\pi Dr \rho g \sin \theta + \pi Dr^2 \rho g (\theta - \frac{1}{2} \sin 2\theta) = mg \quad (\text{eq. 5})$$

$$\text{Also } h = \sqrt{\frac{2S}{\rho g} (1 - \cos \theta)} = 2 \sin \frac{\theta}{2} \sqrt{\frac{S}{\rho g}}$$

$$\text{and } h + l = r \cos \theta + r \quad \text{or}$$

$$2 \sin \frac{\theta}{2} \sqrt{\frac{S}{\rho g}} - r \cos \theta = r - l \quad (\text{eq. 6})$$

The primary measure here was

$$l = 0.083 \pm .001 \text{ cm.}$$

which gives

$$\theta = 72^\circ.8 \quad \text{and}$$

$$h = 0.317 \text{ cm.}$$

The mean value $r = 0.309 \text{ cm.}$ for the radius of the tube had been deduced from the total volume of the torus but direct measurements on the vertical and horizontal diameters of the tube and also on the external and internal diameters of the

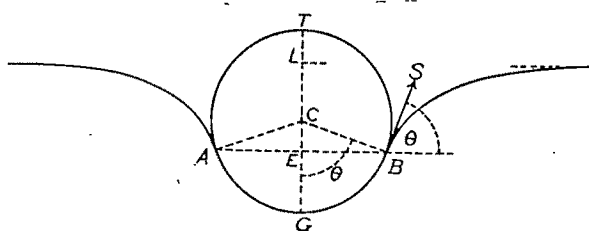


Fig. 2.

torus showed that the tube had suffered a slight distortion in bending it into ring form. The average radius in the plane of the torus was 0.297 cm. As the point B is very near this region it was considered justifiable to adopt $r = 0.300 \text{ cm.}$ for the $r \sin \theta$ term. Substitution of the values given in eq. 5 showed that 2.387 gm. was supported by surface tension; 3.179 gm. by the pressure at the level AB and 1.652 gm. by the water displaced by the portion AEBG. The sum 7.219 gm. is 2 per cent in excess of the weight 7.085 gm. which does not imply any error not fully comprehended in the uncertainties of measurement.

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THE LOWER CRETACEOUS OR COMANCHE SERIES.*

T. W. STANTON.

Eighty-one years ago in the neighborhood of New Braunfels, Texas, Ferdinand Roemer recognized the rocks now referred to the Comanche series as a distinctive unit entirely different in its lithologic and faunal development from all the Cretaceous rocks previously known in the United States. In his brief sketch of the geology of Texas¹ he contrasted it with the Cretaceous east of the highland, or with the Gulf series of the Coastal Plain as we would now say, and compared it with the Mediterranean facies of the European Cretaceous. In another paper² two years later the Cretaceous of the highland was more fully described and its geographic distribution greatly extended while the Gulf series was practically ignored, but in his larger works³ the contrast between the Cretaceous of the highland and the Cretaceous at the foot of the highland, as he finally came to call them, was emphasized. That he misinterpreted the structure and the stratigraphic sequence and on account of that misinterpretation placed the Comanche series above the Gulf series is not at all surprising when we consider how little was known about the stratigraphy of America and particularly the Mesozoic stratigraphy at that time. It was 40 years after Roemer's observations were made before anyone suspected that he was wrong.

Robert T. Hill began his epoch-making stratigraphic studies of the Cretaceous of Texas in 1886, and in the following year he published two papers⁴ in which he named and described the Comanche series, demonstrated that it lies stratigraphically beneath the Gulf series, and brought out the major features of its classification as they are known to-day. During the next 10 or 12 years a rapid succession of small and large

* This paper was presented as a part of a symposium on the Mesozoic and Cenozoic stratigraphy of the Gulf States, at the Nashville meeting of Section E of the American Association for the Advancement of Science, December, 1927. Published by permission of the Director of the U. S. Geological Survey.

¹ This Journal, 2, 358-365, 1846.

² Idem, 6, 21-28, 1848.

³ Texas, Bonn, 1849; Die Kreidebildungen von Texas, Bonn, 1852.

⁴ The topography and geology of the Cross Timbers and surrounding regions in Texas: this Journal, 33, 291-303, 1887.

The Texas section of the American Cretaceous: Idem, 34, 287-309, 1887.

papers by Hill, with the collaboration of T. Wayland Vaughan in some of the later ones, added details of variation in lithologic character, in faunal associations, and in geographic dis-

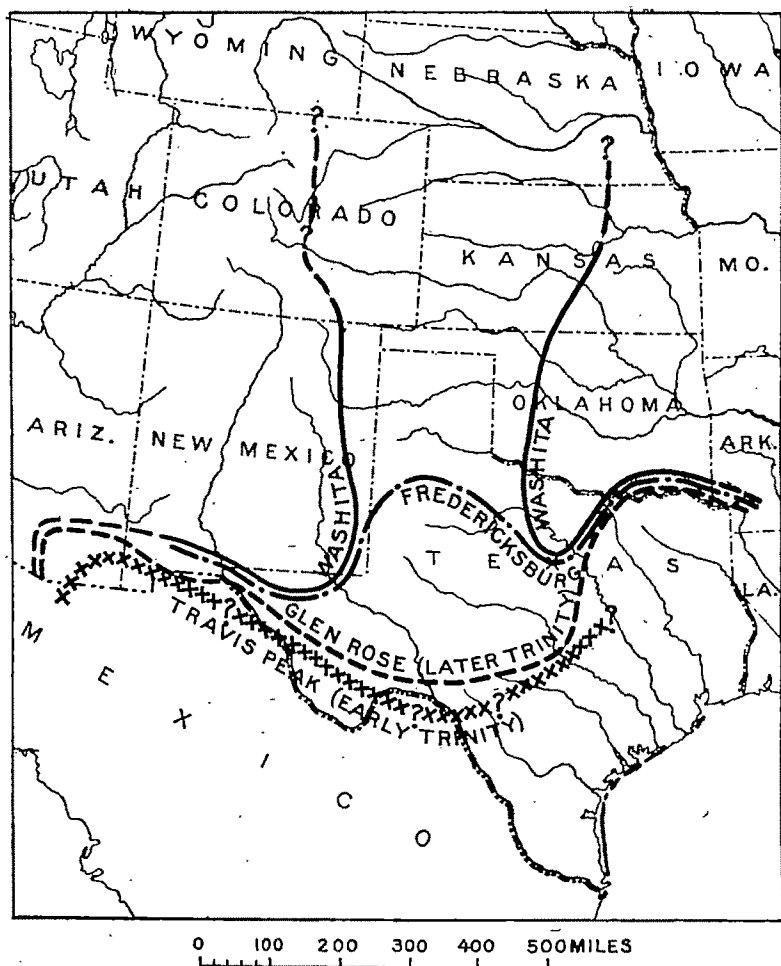


Fig. 1. Map showing approximate strand line of Comanche sea at four stages of its transgression, namely, in Travis Peak, Glen Rose, Fredericksburg, and Washita time.

tribution, which together formed a fair picture of the Comanche series.

Not long after Hill's original announcement F. W. Cragin

recognized the Comanche series in southern Kansas,⁵ and a few years later he showed that some of the rocks of the same age extended northward to middle Kansas.⁶ The further distribution of the Comanche series beyond the limits of the Coastal Plain in Texas, Oklahoma, Colorado, New Mexico, and Arizona has been made known by the work of Marcou, Cummins, Hill, Lee, Darton, Stanton, Ransome, and others and need not be detailed here. It will also be taken for granted that the reader is familiar with the contributions to local and general stratigraphy and paleontology made by Adkins, Böse, Gayle Scott, Stephenson, Whitney, Winton, and many others, all of which have been freely used in this summary.

It may be well to pause here long enough to say that most of the outcrops of the Comanche series are outside the Coastal Plain. In central Texas the line which Roemer drew between his major divisions of the Cretaceous coincides with the boundary between the Coastal Plain and the plateau country, but north of Colorado River and especially north of the Brazos changes in structure make the physiographic boundary less sharply defined, so that in northern Texas, southeastern Oklahoma, and southwestern Arkansas large areas of Comanche rocks fall within the Coastal Plain as usually mapped.

Let me remind you of the major features of the Comanche series as developed in central Texas in the Austin quadrangle.

Washita group	{	Buda limestone 45 ft.
		Del Rio clay 80 ft.
		Georgetown limestone 80 ft.
Fredericksburg group	{	Edwards limestone 300 ft.
		Comanche Peak limestone 40 ft.
		Walnut clay 15 ft.
Trinity group	{	Paluxy sand $\pm$ 100 ft. (absent here but developed to north).
		Glen Rose limestone 450 ft.
		Travis Peak formation 100+ ft.

Here we have three major groups fairly well defined and each with distinctive faunas, though the boundaries between them are not everywhere as sharp as might be desired. The basal one, the Trinity, contains a larger proportion of sand and conglomerate, though in the Glen Rose there is a great

*Cragin, F. W., Geological notes on the region south of the great bend of the Arkansas: Washburn Coll. Lab. Nat. Hist. Bull., 2, 33-37, 1889.

On the Cheyenne sandstone and the Neocomian shales of Kansas: Idem, 69-80, 1890; Am. Geologist, 6, 233-238, 1890; and 7, 23-33, 1891.

*Cragin, F. W., The Mentor beds, a central Kansas terrane of the Comanche series.

development of limestone alternating with marly beds. The Fredericksburg, or middle group, includes more massive limestones with one that contains a great many flints; while in the Washita group at the top the limestones are generally more marly or earthy, and there is a considerable development of clay shale.

The Comanche as a whole in this typical development is a limestone series, and it maintains that character throughout central Texas and far to the southward. To the north and northwest, however, many of the limestones wedge out or are replaced by shales and sandstones, and this change continues progressively until in the most remote areas, as in Kansas, northwestern Oklahoma, and neighboring parts of Colorado and New Mexico, the Comanche rocks, chiefly if not entirely of Washita age, are wholly made up of shales and sandstones. With the changes in lithology there are concomitant changes in fauna, and yet notwithstanding all its diversity the Comanche series has a remarkable unity. In every changing facies, whether of lithology or of fauna, there are connecting links that bind it together into a consistent whole. Its limits, also, are well defined, so far as Texas is concerned, though its upper limit in Kansas and other outlying areas, where its relationship with the Dakota sandstone is involved, will probably long be a subject for discussion.

Some of the variations in lithology and the consequent problems of correlation may now be considered group by group beginning with the Trinity, which is especially troublesome. The initial deposits of the Trinity group in Central Texas, represented by the Travis Peak formation, were laid down in a sea which was transgressing a land of considerable relief. The actual outcrops of that formation are confined to a small area in the Colorado River valley in the northwestern part of the Austin quadrangle and adjacent parts of the Blanco and Burnet quadrangles. Beds of the same age and perhaps others that are somewhat older are found in the southern part of Trans-Pecos Texas, but these have had only superficial study. Rocks containing the characteristic Travis Peak type of ammonites to which Burckhardt has given the name *Dufrenoya* have been recorded by Burckhardt in the State of Durango, Mexico.

In the valley of Cow Creek, near Travis Peak P. O., more than 100 feet of rocks assigned to the Travis Peak overlie the basal conglomerate of the Comanche, and these are followed

by a greater thickness of richly fossiliferous Glen Rose deposits including the zone of *Orbitolina texana*. Toward Burnet, which is only about 20 miles to the northwest, the basal conglomerate rapidly rises until it is clearly rather high in the Glen Rose, above the *Orbitolina* zone, not more than 150 feet beneath the Comanche Peak limestone, and a few miles beyond Burnet the Comanche Peak itself rests directly on Paleozoic rocks. This easily observable rapid change in the age of the basal Comanche deposit is important because of its bearing on the interpretation of Trinity deposits in other areas where the evidence is not so clear. Now observe the behavior of the Glen Rose formation as its outcrops are followed northward in the main Comanche area between the Gulf series on the east and the Paleozoic rocks on the west. First the lenticular Paluxy sand comes in above, separating it from the overlying calcareous deposits of the Fredericksburg group, and at the same time the underlying sands encroach upon it from beneath so that long before Red River is reached the Glen Rose formation as such disappears, and we find only a sandy deposit of 200 to 400 feet in thickness beneath the thin Goodland limestone which represents the calcareous beds of the Fredericksburg. Naturally this basal sand has been assigned to the Trinity group under the name of Trinity sand, or "basement" sand, or Trinity formation, or some local geographic designation, but in northern Texas and across southeastern Oklahoma to Arkansas it is impossible to determine how much of the Trinity group it represents, and it may well be questioned whether at the top it does not include some beds of Fredericksburg age. It is reasonably certain, however, that the fossiliferous beds in Arkansas known as the DeQueen limestone member and the Dierks limestone lentil represent some part of the Glen Rose formation. That any rocks of Travis Peak age occur as far north as Arkansas and Oklahoma seems to me extremely improbable.

A similar condition obtains in the Edwards Plateau and throughout west Texas. The Trinity of the south includes a greater thickness of rocks and older rocks than are found in the northern exposures of so-called Trinity or "basement" sand. The fossiliferous Glen Rose extends but a few miles north of the Southern Pacific Railway on the eastern margin of the Marathon uplift, and apparently it does not go any farther north under the Edwards Plateau. In the El Paso region, however, it is found a little farther north in the

Finlay Mountains, and in the Bisbee district of southeastern Arizona rocks of Glen Rose age with its characteristic fauna cover considerable areas.

In all the high plains country in Texas north of Latitude 32° wherever the base of the Comanche is exposed there is a basal sand which is often conglomeratic and is usually not much more than 100 feet thick—at many places much less than that. In the Fort Stockton quadrangle Adkins⁷ records the thickness as 140 feet, though well logs which he publishes give thicknesses varying from 115 to 460 feet in areas away from the outcrop. Adkins makes the very reasonable suggestion that the basal sand may be of Fredericksburg rather than Trinity age. It is interesting to note in this connection that in the exposures on the eastern margin of the Marathon uplift there is a conspicuous sandstone overlying a good development of fossiliferous Glen Rose limestones and shales and beneath fossiliferous Fredericksburg limestones. Whether it should be classified as Trinity or Fredericksburg is largely a matter of personal preference. Following the precedent established in classifying the Paluxy sand of north central Texas which is in approximately the same stratigraphic position it would be placed in the Trinity, but it may well be in part at least of Fredericksburg age. I have not myself actually traced this upper sandstone to and beyond the line where the fossiliferous Glen Rose wedges out, but it is reasonable to suppose that northward toward Fort Stockton, which is less than 50 miles from the locality mentioned, it passes laterally into the basal sandstone which there immediately underlies limestones which contain a characteristic Fredericksburg fauna.

East of Fort Stockton to San Angelo and other points near the margin of the Permian and Pennsylvanian area and north around the southeast border of the Llano Estacado and in inliers on the plain itself as far north as Latitude 33° the basal sandstone, resting at some localities on Triassic rocks and at others on the Permian, is still in contact with the overlying limestone of Fredericksburg age. The basal sand and gravel in some outcrops, as, for example, southeast of Lamesa, is reduced to a thickness of less than 20 feet. In all this area of Comanche outliers in northwest Texas the basal sand must be either very late Trinity or early Fredericksburg.

⁷ Adkins, W. S., The geology and mineral resources of the Fort Stockton quadrangle: Univ. Texas Bull. 2738, 31, 1927.

In New Mexico, Colorado, northwestern Oklahoma, and southern Kansas it will be shown that the basal sandstone is of still later age.

Before discussing the areal distribution and local variations of the Fredericksburg group it is necessary to define the term with special reference to its upper limit. I am using Fredericksburg in the sense in which it has long been used in central Texas as beginning at the base of the Walnut clay and extending up through the Comanche Peak and Edwards limestones and ending at the top of the Edwards, or at the top of the Goodland limestone in the northern area where the three parts are not recognizable as separate units. I am well aware of the fact that the Kiamichi clay has been classified as the upper part of the Fredericksburg group by Winton, Adkins, and Scott in recent papers,⁸ but it seems to me that the facts of geographic distribution as well as past usage are strongly in favor of retaining the Kiamichi as the basal formation of the overlying Washita group.

It is well known that in central Texas the Fredericksburg includes about 350 feet of limestones and that the most conspicuous and distinctive feature in it is the thick heavy-bedded flint-bearing Edwards limestone with its peculiar fauna consisting largely of attached reef-dwelling forms belonging to the Rudistae, the Caprinidae, and the Chamidae. Northward the Edwards thins and loses its characteristic features until north of Brazos River it is no longer recognizable as a distinct formation, and all the Fredericksburg limestones are merged into the Goodland limestone which at the north line of Texas and in Oklahoma is reduced to a thickness of 25 feet. All the sandy beds beneath the Goodland are for convenience referred to the Trinity, though the fauna indicates that at least the upper part of the sand is of Fredericksburg age.

The suggestion has already been made that the basal sand may be in part if not wholly of Fredericksburg age in the high plains area near, and in the southern part of, the Llano Estacado where limestones with characteristic Fredericksburg faunas, including the reef facies, extend far beyond the out-

⁸Winton, W. M., The geology of Denton County: Univ. Texas Bull. 2544, 1925.

Adkins, W. S., The geology and mineral resources of the Fort Stockton quadrangle: Univ. Texas Bull. 2738, 1927.

Scott, Gayle, Etudes stratigraphiques et paléontologiques sur les terrains crétacés du Texas, 1926.

crops of the overlying Washita. It is probable that the Washita rocks once covered the Fredericksburg in all this area because they are found in good development farther west in the Fort Stockton region, and a littoral facies of the Washita with characteristic fauna occurs in outliers west of the Llano Estacado in eastern New Mexico as well as farther north in Oklahoma, Colorado, and Kansas.

In southwest Texas in the Edwards Plateau and westward to Devils River, Pecos River, and beyond mistakes have been made in the past in drawing the boundary between the Fredericksburg and the Washita, and there is still difficulty in placing isolated outcrops or in referring small collections of fossils to their proper stratigraphic position because the peculiar lithology and the reef faunal facies of the Edwards recurs in the Washita near the top of the Georgetown limestone and, according to Adkins, at another level between that and the Edwards. This condition is particularly evident in the Edwards Plateau near Brackettville on the southern border and near Rock Springs at the summit of the plateau and in the gorges of Devils River and Pecos River near their mouths.

The true stratigraphic relations of these limestones in the vicinity of Del Rio were recognized some years ago by Udden,⁹ who named the massive limestone of Edwards aspect along Devils River the Devils River limestone and stated that it includes the equivalent of the Georgetown limestone and is therefore in part of Washita age. A similar development in the Fort Stockton region has been recorded by Hill and Adkins.¹⁰ I wish to record from my own observations that the entire thickness of limestone in the gorge of Devils River at the crossing of the Comstock road and for some miles above is of Georgetown age. At the top just beneath the Del Rio clay the limestone contains the recurrent reef facies of the Edwards fauna including *Chondrodonta*, *Caprinula*, and numerous specimens of *Nerinea*, while beds at the bottom of the gorge yield *Hemiaster elegans*, *Ostrea carinata*, and *Pervinqueria leonensis*. In the Brackettville quadrangle also the Del Rio clay rests directly on massive limestone of the Edwards type containing *Caprinula* and *Nerinea*, and even on top of the

⁹ Udden, J. A., Report on a geological Survey of the lands belonging to the New York and Texas Land Company (Ltd.) in the upper Rio Grande embayment in Texas. Augustana Library Pub. No. 6, 1907.

¹⁰ Hill, R. T., Two limestone formations of Texas which transgress time diagonally: Science, N. S., 53, 190-191, 1921.

Adkins, W. S., Geology and mineral resources of the Fort Stockton quadrangle: Univ. Texas Bull. 2738, 1927.

Edwards Plateau at Rock Springs a few feet of Del Rio clay with *Exogyra arietina* rests on the same massive limestone and is overlain by a thin remnant of Buda limestone, which is the actual top of the Comanche series.

The changes in the lithology and to a less extent in the faunas of the Washita group from central Texas at Austin to northern Texas in the Denison region are too well known to require review at this time.

Elsewhere the principal interest in the variations and correlation of the Washita group lies in the marginal deposits and outliers far beyond the borders of the main area of Comanche rocks. For example, in eastern New Mexico, west of the Llano Estacado, there are outliers of Comanche near Rogers and at Tucumcari which according to my interpretation contains nothing older than Washita. There is a thin basal sandstone which at Tucumcari is reported to have yielded dicotyledonous plants. Above that are marine shale and sandstone less than 100 feet thick containing *Gryphaea corrugata*, *G. tucumcari* and near the top *Pervinqueria trinodosa*, and this fossiliferous bed is overlain by a sandstone that has been referred to the Dakota. The fossils call for correlation with the Kiamichi and the Duck Creek of northern Texas, and the sandstone beneath is naturally regarded as the initial deposit of the same sea in which the fossiliferous marine beds were laid down. The same and additional fossils belonging to this fauna are found in several areas in western Oklahoma and along the Cimarron in the northwest corner of that State and in adjacent areas of New Mexico and Colorado. How far deposits of this age extend to the north along the foothills of the Front Range in Colorado and beyond is still an open question.

In southwestern Kansas the section is like that at Tucumcari but with a fuller development of both rocks and fossils. The basal sandstone, named Cheyenne sandstone by Cragin, contains a dicotyledonous flora recently described by Berry,¹¹ who considers it to be older than the Dakota flora but of Upper Cretaceous age. Berry apparently considers it to be Cenomanian, though he does not distinctly say so.

The Kiowa shale, overlying the Cheyenne sandstone, contains a varied invertebrate fauna in which *Gryphaea navia*, *G. corrugata*, and *G. tucumcari* play a prominent part. With these and many other pelecypods and gastropods are a few

¹¹ Berry, E. W., The flora of the Cheyenne sandstone of Kansas: U. S. Geol. Survey Prof. Paper 129, 199-224, 1922.

keeled ammonites of the type which has recently been named *Oxytropidoceras*. Keeled ammonites are a conspicuous element in the Comanche fauna commencing in the Fredericksburg and continuing through most of the Washita. Most of these fall into two principal groups, the earlier of which has been referred to *Oxytropidoceras*, which is characterized by compressed whorls, a trenchant keel, and rather subdued sculpture. It is abundant in the Goodland limestone and extends up into the Kiamichi formation, where it is occasionally associated with the earliest representatives of the other more robust group, called *Pervinquieria*, of which the European *Ammonites inflatus* is the type. *Pervinquieria* is abundantly represented in the Duck Creek and Fort Worth limestones of northern Texas and extends at least to the top of the Georgetown limestone in central Texas. The faunal evidence seems to be fairly convincing that the lower part at least of the Kiowa shale is of Kiamichi age. All the invertebrate evidence strongly indicates that it is earlier than the *Pervinquieria inflata* zone which has sometimes been classified as Cenomanian, but according to the recent studies of Spath in England and of leading geologists in France the *inflata* zone is of Albian age, as Gayle Scott has pointed out. If this be so then the Cheyenne sandstone with its flora which underlies the Kiowa shale must also be as old as the Albian. It may be that the upper part of the Kiowa shale is of later age than the Kiamichi and it is still more probable that the Mentor formation of central Kansas should be correlated with some higher formation of the Washita group as developed in the Denison region, but the paleontologic evidence does not yet permit definite correlation with any one of these units. The limit of the northward extension of beds of approximately the same age along the eastern foothills of the Front Range in Colorado and possibly into southern Wyoming is not definitely established.

With these exceptions and with the further exception of some of the basal deposits of the Trinity in the region beyond Pecos River and of the underground extension of the Comanche beneath the Tertiary deposits of the coastal plain on which data are not accessible to me, the intercorrelation of the various parts of the Comanche series are fairly well established. Fortunately the wide geographic distribution of many of the easily recognized zone fossils has made these intercorrelations definite and positive by furnishing numerous checks on the usual means of identification. Among these

widely distributed zone fossils I may mention *Orbitolina texana*, *Exogyra texana*, *Exogyra arietina*, *Gryphaea marcoui*, *G. navia*, *G. tucumcari*, *Turritiles brazoensis* and many species of the keeled ammonites already mentioned. The establishment of these local correlations and the determination that the Comanche series is a natural major unit in the stratigraphy of the Southwest, are to my mind much more important than minute correlation with the units of European stratigraphy, however interesting that may be. It may be said in passing that the correlation of the Travis Peak formation with the upper Aptian has been fairly well established by the presence of ammonites belonging to the group of *Dufrenoya furcata*, and that the great development of ammonites related to *Pervinqueria inflata* in the Washita group justifies the correlation of a large part of the Washita if not the whole of it with the zone of *Pervinqueria inflata* in the broad sense, as used by many European geologists, and this is really a definite correlation, entirely independent of the much debated question whether the zone should be called Albian or Vraconian or Cenomanian.

Another important fact which I would emphasize is that throughout the long Comanche epoch the sea was encroaching on the land. There may have been occasional regressions, but each successive transgression of the sea went farther than the one that preceded it, so that the Fredericksburg sea covered more of the present land than had been covered by the Trinity and the Washita sea covered perhaps twice as much as the Fredericksburg. The accompanying map (Fig. 1) shows the approximate border of the Comanche sea, as indicated by well determined marine invertebrate faunas, at four stages of its transgression, namely, in Travis Peak, Glen Rose, Fredericksburg, and Washita time. It is safe to assume that the actual strand line in each case was somewhat further inland than the present known extent of the fossiliferous deposits of the epoch, but the lines of the map probably represent truthfully the relative progress of the sea's advance. Possible extensions are indicated by broken lines and question marks.

I have not ventured to draw an eastern boundary under the Tertiary cover. Fossiliferous Trinity rocks are known in deep wells in northwestern Louisiana. I have no record of marine Comanche rocks east of the Mississippi River.

OSTRACODA FROM THE TRENTON LIMESTONE OF NASHVILLE, TENNESSEE.

STUART RAE BURN KIRK.

Contributions from the Paleontological Laboratory, Peabody Museum,
Yale University, New Haven, Connecticut.

Some months ago Professor Schuchert entrusted a collection of limestone specimens to the writer for the purpose of cleaning and extracting the fossil ostracods they contained. This collection Schuchert made in August, 1907, from the Trenton (Catheys) limestone near Reservoir Hill, Nashville, Tennessee, apparently the same horizon as that from which Ulrich obtained some of his large representatives of the Leperditidae. The present paper deals with the description of the ostracod fauna of this limestone.

The rock is compact, gray and crystalline and in it single valves of a large leperditian, from one-half to three-quarters of an inch in length, are abundantly scattered, these valves standing out prominently on account of their size and distinctive, black, polished surfaces. It has been found that the great majority are referable to the species *Isochilina ampla* Ulrich. Close study of some seventy or more valves, however, has thrown doubt upon the generic character of the species and has suggested the appended discussion of the genera *Leperditia* and *Isochilina*.

Among the other species described in this paper the most interesting is a *Drepanella*, represented by at least two varieties, whose structural characters indicate close affinity with *Klædenia* and thus may throw some light on the derivation of the latter form.

Minute ostracods, probably belonging to more than one genus, are abundant, but owing to their very small size and the difficulty of extracting or clearing them intact from the rock matrix, it has been found impossible to make identification of these.

Leperditia ampla (Ulrich).

(Fig. 4 a-h.)

Isochilina ampla Ulrich, Jour. Cincinnati Soc. Nat. Hist., 13, No. 4, p. 179, pl. 11, figs. 8a-8d, 1891.

The specimens of this locally abundant and distinctive species agree very closely with Ulrich's description. Thus the

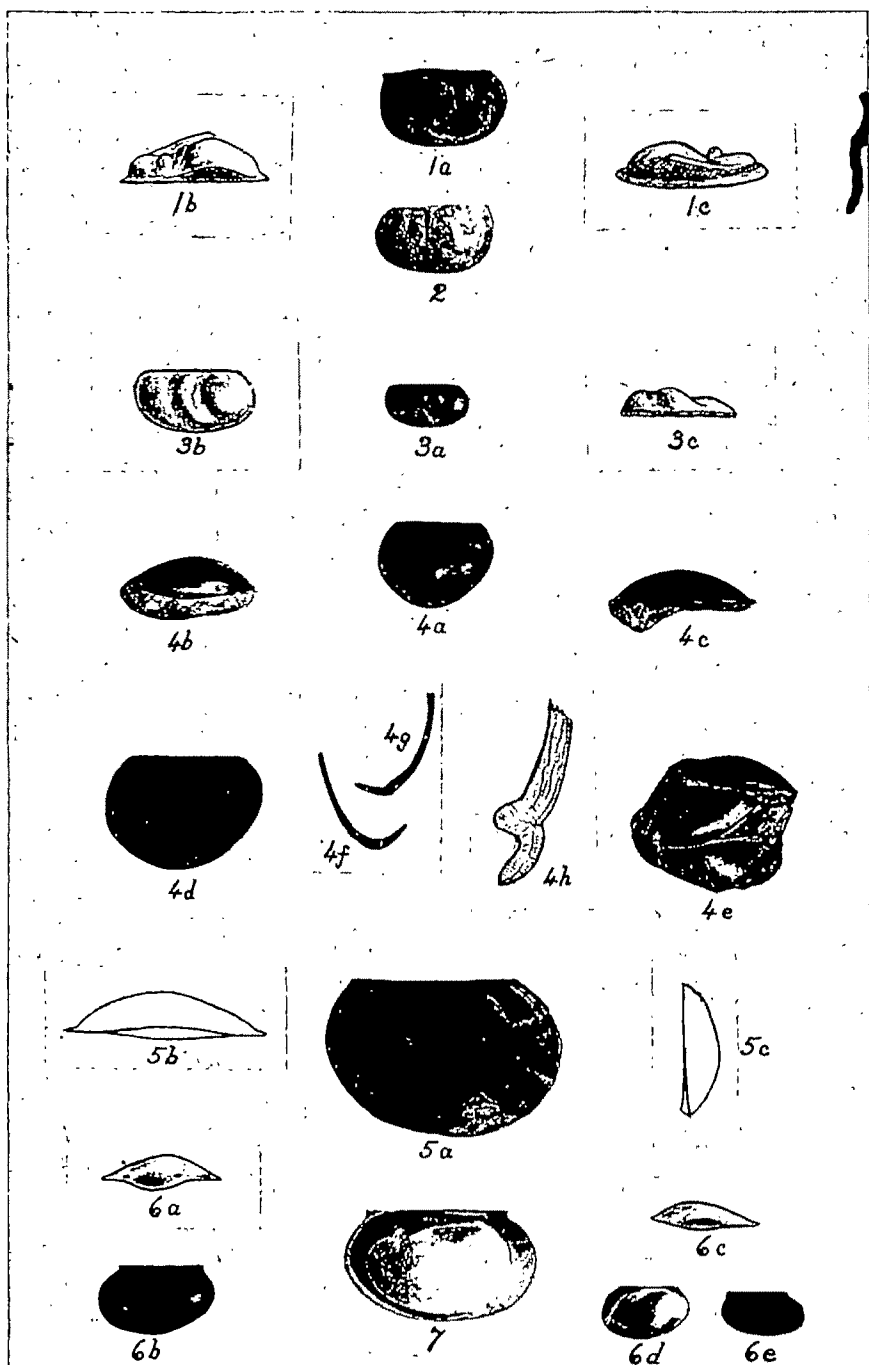
general outline, obliquity and convexity of the valves, the oval reticulated muscle spot, the small eye tubercle and the depression behind it, the steepness of the cardinal slope, the width of the marginal flange and its absence ventrally, the obtuse angularity of the posterior cardinal extremity and the dark, polished surface are all perfectly matched, and leave no room for doubt as to the identity of the species. In reaching this conclusion the writer has had for comparison, besides Ulrich's published account of the species, referred to above (where he figures only a right valve), a "metatype" specimen bearing two almost complete left valves and labelled as coming also from the Trenton group of Nashville, Tennessee. These "metatype" specimens will be included in the discussion of the species that follows.

Minor features, not mentioned by Ulrich, are the fact that the cardinal slope presents a slightly flattened and triangular appearance, that the reticulating, granulose lines that radiate from the muscle spot are quite visible from the exterior, in the better specimens, and that the surface, instead of being perfectly smooth, is minutely pitted along these lines. It may also be remarked that the pointed anterior extremity of the dorsal margin, mentioned and figured by Ulrich, is not shown by any of the specimens.

But the character of the valves on which generic diagnosis must depend is their essential, though not strong, inequality, for it is found that there is a distinct ventral overlap of the right valve over the left. Although no instance has been found of two valves in their natural association, the existence of such an overlap is proved beyond doubt by the following facts.

Right valves are always noticeably higher than left valves of similar length. (In a right and left valve, both 16 mm. long, the difference in height amounts to 1 mm.) This extra height is shown in the stronger convexity of the ventral edge of right valves, and in these the point of greatest convexity, and hence the greatest height, is only slightly more than half way from the front. The ventral edge of a left valve is less strongly convex and its greatest height very near to the posterior end.

The ventral edge of a right valve shows a thickening and inward, lip-like curvature, comparable in kind with that of *Leperditia tumidula* Ulrich. This inwardly curved portion dies out to front and rear gradually and not suddenly, but



Figs. 1-7.

its more strongly projecting part is bounded by two small pits which terminate the anterior and posterior portions of the marginal flange, respectively. Internal moulds and transverse sections show these pits to be represented internally by pronounced papillae.¹ The distance between the pits is slightly less than half the total length of the valve.

In a position corresponding to the right valve overlap, just described, there is an inwardly sloping area on the left valve, sharply marked off from the rest of the valve surface by a distinct angulation. The surface of this sloping area is faintly elevated and gives rise to the false appearance of the presence of a thin, overlapping right valve margin. The angular edge of the area is along a line which is gently curved in the same sense as the convexity of the valve and thus corresponds to the projecting curvature of the right valve overlap. As seen from the outer surface, the flange fades out and completely disappears ventrally, but it is a continuous feature on an internal mould, due to thickening of the shell in this region.

The left valves also differ from right valves in usually possessing a more or less faint, elongate swelling in the postero-dorsal region.

¹ Cf. Ulrich, Jour. Cincinnati Soc. Nat. Hist., 13, No. 4, 173-174, 1891; Ulrich and Bassler, Md. Geol., Surv., Silurian, 295, fig. 13, No. 5, 1923.

Figs. 1 a-c. *Drepanella progressa*, n. sp.

1 a, left valve (x 6); 1 b, same, dorsal view; 1 c, same, ventral view.

Fig. 2. *Drepanella progressa* var. *reticulata*, n. var.

Right valve (x 8).

Figs. 3 a-c. *Ctenobolbina ciliata* var. *parva*, n. var.

3 a, Left valve (x 9); 3 b, camera lucida drawing of same (x 13); 3 c, same, dorsal view (x 13).

Figs. 4 a-h. *Leperditia ampla* (Ulrich).

4 a, Small right valve (x 1¼); 4 b, ventral view of a right valve; 4 c, same view of a left valve; 4 d, right valve of an average-sized adult (x 1¼); 4 e, a group of shells showing ventral edges of a right and a left valve; 4 f, transverse section of a right valve showing the ventral overlap; 4 g, transverse section of a left valve showing ventral infold; 4 h, transverse section through one of the ventral pits of a right valve, greatly enlarged.

Figs. 5 a-c. *Leperditia ampla* var. *nashvillensis*, n. var.

5 a, left valve (x 1⅓); 5 b and c, ventral and anterior views showing the ventral edge.

Figs. 6 a-e. *Leperditia catheyensis*, n. sp.

6 a, Drawing of ventral view of right valve; 6 b, a small right valve (x 4); 6 c, drawing of ventral view of left valve; 6 d, a large right valve (x 1¼); 6 e, a small left valve (x 3).

Fig. 7. *Isophilina saffordi* Ulrich.

Left valve (x 1½).

The overlapping and unequal character of the valves, as outlined in the preceding paragraphs, makes it necessary, in the opinion of the writer, to remove this species to the genus *Leperditia*. The bearing of this decision on the generic diagnoses of *Leperditia* and *Isochilina* is discussed later.

Among the seventy or more specimens in the collection some individual variation is noticeable. Except for the form described in this paper as *Leperditia ampla* var. *nashvillensis*, however, varietal differentiation does not seem to be called for.

In describing this species as an *Isochilina*, Ulrich remarked on the probability of its nearest relationship being with *I. jonesi* Wetherby. While its relationship to this species may not be distant, it appears, in view of the structural characters given above, that it bears closest structural resemblance to *Leperditia appressa* Ulrich, from which it differs in its greater size and much stronger tumidity, and to *L. tumidula* Ulrich, from which it differs also in size, but more strongly in the absence of the strong ventral tumidity that is so marked a feature of that species. The thickening along the postero-dorsal edge of the left valve associates it with the two species mentioned and possibly also with *L. linneyi* Ulrich and others,² including *L. catheyensis* of this paper.

Note on the genera Isochilina and Leperditia.

Jones, the author of the genus *Isochilina*, regarded this as an equivalved form. Recognizing it first as a sub-genus of *Leperditia*, he states it to be "Equivolve; the margins of the valves meeting uniformly, not overlapping as in *Leperditia*."³ Later, in speaking of the two previously described species of the subgenus, he states that "they are possibly members of a distinct genus"⁴ and gives generic rank to *Isochilina*.

The misconception of *Isochilina* as having the valves equal in every respect was repeated widely in the literature until Ulrich and Bassler, in redefining the genus, pointed out that "in reality within the left valve there is a sloping area that is overlapped by a corresponding bevelled edge of the right valve."⁵ In doing so these authors have shown the essential structural unity of *Isochilina* with *Leperditia*, for the differ-

² See Ulrich, op. cit., p. 175.

³ Ann. Mag. Nat. Hist., 3d ser., 1, p. 248, 1858.

⁴ Monthly Microsc. Jour., 4, p. 191, 1870.

⁵ Op. cit., p. 295.

ence between these two genera appears to be really only one of degree and not of kind. Even in well accepted species of *Isochilina*, such, for instance, as *I. jonesi* Wetherby, where there is a continuous marginal flange on both valves, a slight external overlap is represented by curvature of the right valve flange towards and over the flange of the left valve. This is well shown in Ulrich and Bassler's diagrammatic figures of *I. jonesi*.⁶ Ignoring this feature, which, after all, only makes for very minor dissimilarity (externally) of the valves, these authors state in defining *Isochilina* that "exteriorly the valves do not overlap, but seem to be equal in every respect." But between this and *Leperditia* as redefined by them, there is an indefinite but apparently large gap, for they say of the latter genus that it has its "valves *strongly unequal*, the right the larger and *widely overlapping* the ventral edge of the left" (italics mine). While the personal factor must enter here, it is certain that the overlap in such a form as *L. ampla* (Ulrich) could not be called *wide* and it is also very doubtful if the valves would be recognized as *strongly unequal*. In other words, there are structurally intermediate forms which do not fall readily into either genus as at present defined, so that the gap does not really exist and *Leperditia* can be regarded as grading into *Isochilina*.

Three possible ways out of the difficulty suggest themselves. (1) Accepting the new restrictions of Ulrich and Bassler, to create a new genus to accommodate border-line forms of slight external overlap, between *Leperditia* with its wide overlap and *Isochilina* with its negligible overlap. (2) In view of the apparently gradational character of the supposedly essential features, to recognize only one broad genus. (3) To retain the present genera, broadening the definition of *Leperditia* so as to include all forms of appreciable external overlap. The first of these schemes would be unnatural and the determination of a boundary line between *Leperditia* and the new genus would have to be arbitrary. There does not seem to be any call for a new genus. Probably the second scheme is the most natural. (Under it *Isochilina* might still be recognized for convenience of structural subdivision, but returned to the status of sub-genus first assigned to it by Jones.) But where so little is known of natural relationship, and classification is largely a matter of convenient description,

⁶ Ibid., Fig. 13, Nos. 7 and 8.

and in view of the firm establishment of *Isochilina* in the literature, it seems to be justifiable and even desirable to retain it as a genus. Accordingly the third and most conservative policy is adopted here.

Separation of *Isochilina* from *Leperditia* on the evidence of single valve specimens may sometimes be difficult, unless the ventral edges are well-preserved and exposed. Probably the equality in height of right and left valves (precluding any possibility of pronounced external overlap) and the absence of ventral thickening, usually, though not always indicated by the continuation of a distinct flange round the ventral border on both valves,⁷ remain the most practical criteria for the determination of *Isochilina*.

Leperditia ampla var. *nashvillensis*, n. var.

(Fig. 5 a-c.)

This form, represented by a single, large, left valve, is considered to differ sufficiently from all the other specimens of *L. ampla* (Ulrich) to necessitate its separation as a variety.

Measurements: length 21.7 mm., height 14.5 mm., thickness 5 mm.?, hinge 15.4 mm.

The valve is sub-rectangular, differing from *L. ampla* in the absence of any notable obliquity. The marginal flange is somewhat narrower than in the typical forms of the species. It is evenly convex with the point of greatest convexity slightly below the center, the convexity being less strong than in *L. ampla*. The eye tubercle is very small and acute and the sulcus behind it is faint. The ventral margin is like that of *L. ampla*.

The slightly damaged valve that represents this variety is the largest in the collection.

Leperditia catheyensis, n. sp.

(Fig. 6 a-e.)

This is rather a common species, represented by numerous small to medium-sized specimens of both valves, ranging in

⁷ Among the American species of *Isochilina* listed by Bassler (U. S. Nat. Mus. Bull. 92, pp. 672-674, 1915), *I. panolensis* Foerste has "no flat marginal rim distinctly defined from the general convexity of the main body of the valve" (Bull. Ky. Geol. Surv., 7, 329, 1906), *I. labrosa* Jones is doubtful in regard to the ventral continuation of the rim (Ann. Mag. Hist., 6th ser., 3, p. 384, 1889), and in *I. seelyi* (Whitfield) the flange practically dies out for a short distance along the ventral edge.

length from about 3 mm. to 8 mm. In no case have two valves been found in their natural association.

Measurements of two right valves:

Length 8 mm., height 5 mm., thickness 1.5 mm.?, hinge 5.4 mm.
" 5.2 mm., " 3 mm., " 1 mm.?, " 3.5 mm.

Measurements of two left valves:

Length 7 mm., height 4 mm., thickness 1.2 mm.?, hinge 4.7 mm.
" 3.6 mm., " 2 mm., " .7 mm.?, " 2.7 mm.

The right valve is elongate and subelliptical; slightly oblique and wider posteriorly, with greatest height just behind the middle. Cardinal edge straight, with both extremities acutely angular. Marginal flange rather narrow and not sharply defined; developed anteriorly and posteriorly, but absent for the greater part of the length of the ventral edge. Eye tubercle small; situated antero-dorsally. Large, ovate muscle spot below and behind the eye tubercle, two-fifths of the valve length from the front and slightly above the middle line. Point of greatest convexity approximately central, at the posterior edge of the muscle spot. Valve strongly convex with steep cardinal slope and marked ventral tumidity. The ventral edge of the valve is abruptly bent in at a right angle to form a more or less flattened, projecting lip which extends for half the length of the valve. Three small pits occur near the ventral edge; one shortly below the extreme anterior portion of the valve, marking the ventral termination of the distinct portion of the flange, a second behind this where the flange finally dies out and opposite the beginning of the pronounced overlap, and the third opposite the posterior end of the overlap and terminating the posterior flange.

The left valve is, in general, similar to the right valve, differing mainly in being less high, in having no marked convexity on the ventral border and in having its greatest height near the posterior end. The apex of the convexity is well forward and the ventral edge is very sharply deflected to form a flattened infold, corresponding to the overlap of the right valve. A distinct, elongate, postero-dorsal swelling is present on the largest specimen. In young (small) specimens this feature, although not absent, is much less pronounced.

The valves are smooth, black or brown and polished.

This species is, without doubt, closely related to *L. linneyi* Ulrich, differing from it mainly in its more elongated and less oblique form.

Isochilina saffordi Ulrich

(Fig. 7.)

Isochilina saffordi Ulrich, Jour. Cincinnati Soc. Nat. Hist., 13, No. 4, p. 178, pl. 11, figs. 10, a-d, 1891.

This species is represented in the collection by a single specimen of a left valve. The specimen has the margin well preserved, but the carapace is largely removed towards the center, leaving only an internal mould.

Agreement with *I. saffordi* Ulrich is so close as to place the specific identification beyond doubt. Ulrich's figure, however, shows no angulation of the posterior end of the dorsal line and he states that "the rounded character of the postero-dorsal edge" is a distinctive feature of the species; while the specimen on hand has the postero-dorsal edge acutely pointed. Minor variations in the character of the hinge-line terminations of leperditian valves are common and are probably of no particular taxonomic significance, nevertheless it is felt to be desirable to figure the species here to show this feature.

Ctenobolbina ciliata var. *parva*, n. var.

(Fig. 3 a-c.)

Two single valves, one left and one right, represent this variety. The description which follows is based on the left valve which is in the better state of preservation of the two.

Measurements: Length 1.2 mm., height .6 mm.

Valve small and subrectangular with the ends practically equal and only slightly oblique. Dorsal edge straight with rounded terminations. Median sulcus strong and arcuate, separating the posterior and anterior lobes. Anterior lobe divided by a less pronounced, oblique sulcus. Posterior part of this lobe prominent and ridge-like, bearing a small but pronounced tubercle near its ventral extremity.⁸ Posterior lobe most prominent, occupying a little more than one-third of the length of the valve. On its inner slope and towards the dorsal border, this lobe bears a small node, presumably representing a median lobe. The usual "frill" or flattened border of the genus is represented only by an inconspicuous, angular ridge, not high enough to conceal the contact margin. The margin appears to be smooth as does the surface of the valve.

⁸ Cf. Jones, Quart. Geol. Soc. London, 46, pl. 3, figs. 12a and 14a.

Agreement with *C. ciliata* (Emmons) in general form and lobation is close. The variety differs, however, from the typical form of the species in the smooth contact margin and surface, the improminence of the infra-marginal ridge and in the presence of the median node, borne by the anterior portion of the posterior lobe. The presence of such a node is not recorded in any of the descriptions of *C. ciliata*, but it may be noted that Ruedemann's figures of a specimen from the "Upper Utica shale, Menands, Albany Co., N. Y."⁹ and referred to this species, show a similar feature, although no remark is made about it in the text. In addition, examination of the Peabody Museum specimens of *C. ciliata*, from the "Utica group" of various localities in Ohio and Kentucky, has shown that the presence of such a node is by no means an uncommon feature of the species. In none of these, however, is the node as distinct as in the variety here described.

The median node of *C. ciliata* var. *parva* is slightly less prominent than that of *C. subcrassa* Ulrich and much smaller in area than that of *C. denticula* Ulrich and Bassler. From what has been said above, it is clear that the small median node cannot be made the basis of inclusion of the variety with the group of *C. subcrassa*.¹⁰ It belongs to the group of *C. ciliata*, despite the statement of Ulrich and Bassler that "in the *ciliata* section of *Ctenobolbina* the median lobe is undistinguishably merged in the larger posterior bulb which characterizes this section."¹¹ The presence of the distinguishable median lobe suggests that this early variety may represent a slight approach, in a backward direction, towards the previously established *C. subcrassa* section.

Drepanella progressa, n. sp.

(Fig. 1 a-c.)

This new species is based on three well-preserved left valves.

Measurements: Length 2.5 mm., height 1.6 mm.

" 2.4 mm., " 1.5 mm.

Valves small and subquadrate with the ventral angles uniformly rounded and the ventral margin gently curved. Hinge

⁹ Bull. N. Y. State Mus., No. 42, p. 575, pl. 2, figs. 8 and 9, 1901.

¹⁰ Ulrich and Bassler, Proc. U. S. Nat. Mus., 35, p. 309, 310, 1908.

¹¹ Ibid., p. 296.

line long and straight with slightly produced and acute anterior extremity and obtuse posterior angle. Valve obese; crossed by a strong median furrow which spreads and fades out with a slight backward curvature towards the ventral expansion of the valve and by a posterior furrow which is much less strong and dies out half way across the valve. Median lobe small but prominent, rounded and bulbous, with a width about one-eighth of the length of the valve; situated approximately one-third of the length forward and one-third of the height from the dorsal edge and merging below with the posterior lobe. Posterior lobe less elevated but well defined, especially posteriorly, and bluntly terminating at the dorsal edge. Anterior lobe large and strongly convex, ending dorsally in a blunt ridge which arches slightly above and away from the hinge margin. Within the tumid ventral margin of the valve is a small, sharp ridge, more or less parallel with the margin. Towards the anterior end this ridge increases in prominence, curving slightly upwards and ending abruptly in a short projection immediately below the middle of the anterior lobe. Posteriorly the ridge passes into and becomes merged with the posterior lobe. A marginal brim or flange surrounds the valve, terminally and ventrally; widest posteriorly and narrowest ventrally, and sharply marked off from the convex portion of the valve by a steep slope all round. The valve surface actually overhangs the brim ventrally, due to the strong tumidity in this region. The surface is apparently smooth and the shell very thick, the greatest thickness being over the median and posterior lobes.

From the foregoing description it will be seen that this interesting species has features in common with both *Drepanella* and *Klædenia*, so that it is a matter of some difficulty to place it generically. The general aspect of the lobation is essentially *Klædenia*-like, although the length of the median sulcus is a feature not characteristic of that genus. The small size and relatively low and markedly posterior position of the median lobe differ from the features of the typical Silurian species of *Klædenia*, but are paralleled in the Trenton *K. prænuntia* Ulrich and Bassler.¹² At first the writer was

¹²In 1908 (op. cit., p. 305) Ulrich and Bassler referred the Ordovician species *K. initialis* and *K. prænuntia* to the genus *Klædenia* "with some misgivings." Their more recent restriction of the genus to Silurian and Devonian (Md. Geol. Surv., Silurian, p. 307, 1923), seems to indicate that they no longer regard these Ordovician forms as true *Klædenias*.

inclined to refer the species to *Klædenia*, but after consideration decided to accept the presence of the postero-ventral ridge as the most essential diagnostic character and consequently to place it with *Drepanella*.

Although differing from a typical *Drepanella* in the more or less uniform convexity of the valve and the absence of isolated nodes, this form may be compared with *D. elongata* Ulrich, of which Ulrich and Bassler state that it "might be classed as a *Klædenia* if it had not the characteristic, sub-marginal ridge."¹³ The ridge is shorter and less pronounced than in that species and is not distinguishable where it passes into the posterior lobe. The closest resemblance, however, is probably to *D. richardsoni* (Miller), in which the ridge is remarkably similar although more pronounced.

In discussing the possible ancestry of *Klædenia*, Ulrich and Bassler suggest four possible sources of the genus.¹⁴ One of these is derivation through *Drepanella*, the species *K. præ-nuntia* being regarded as structurally more or less intermediate between such a form as *D. elongata* and a typical *Klædenia*. It would seem that the discovery of this new *Drepanella*, so very clearly a border-line form, furnishes additional and strong evidence in favor of the evolution of the *Klædenias* (or at least some of them) out of *Drepanella*.

Drepanella progressa var. *reticulata*, n. var.

(Fig. 2.)

Accompanying the species just described are several specimens of right and left valves of a similar form. Unfortunately none of these is quite complete. The only essential difference from *D. progressa* is the presence of a prominent and rather coarse reticulate pattern on the surface. This pattern is strongly developed on the anterior and posterior lobes, but is absent from the bulbous expansion of the small median lobe, as it is also from the sulci. A postero-ventral ridge is present, but is not prominent and is free from reticulation. From specimens which show the antero-dorsal edge it appears that elevation of this portion of the anterior lobe is not so pronounced as in the typical form of the species.

¹³ Proc. U. S. Nat. Mus., 35, p. 312, 1908.

¹⁴ Ibid., p. 303.

The surface reticulation in different fragmentary specimens shows differing degrees of coarseness and prominence, possibly indicating varietal differences; but in the absence of more complete evidence no definite pronouncement can be made.

The variety as here described is based on the right valve which is figured.

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STUDIES IN MINERAL SEPARATION IN A FINELY DIVIDED STATE.

R. C. EMMONS.

INTRODUCTION.

This paper is a report of progress in some experiments made to find a new means of affecting minerals selectively with a view to applying the selective force to the problem of separating minerals in the dry state and in the finely divided state. Not only is there no satisfactory method of separation available to the more fine-grained mixtures, but those resorted to are mostly wet methods and are attended by the objections of such methods. A distinctly selective force has been found by the writer. It is progressively more effective on the more finely divided materials and has been tested out on several minerals. This has in turn been applied to the final problem of the separation of mixtures and has met with some degree of success but not in the measure hoped for, in that the force of adhesion has not been satisfactorily overcome. However some time has passed since the original development, and the final obstacle continues to remain. The results and procedure are therefore presented, in part, for their limited applicability but mainly in the hope that other investigators may be interested and may succeed in the last step where the writer has thus far failed. If successfully completed the writer believes that the newly applied forces herein outlined will serve mineralogists and petrographers a real purpose.

If mineral powder is made to fall in a dust stream through a beam of light in a closed system and at suitably low gas pressures, then those mineral grains against which gas pressure is developed are deflected and other mineral grains are not. Since ultimately the deflecting force is the incident light, then the finer the state of division and the greater proportionately is the exposed surface, so is the force progressively more effective. The outstanding characteristic which makes a mineral responsive to the applied force is heat absorption, which is closely related to color.

THE PROBLEM.

The problem of the mineralogical analysis of fine-grained rocks may be reviewed best by outlining the principal require-

ments that must be satisfied. Only those requirements are listed which relate to the difficulties encountered in handling heterogeneous material of this state of division.

The individual minerals are closely associated in any compact rock but they are particularly closely associated in a fine-grained compact rock. Extreme intimacy of association is not always due to fineness of texture but sometimes to the presence of inclusions in the larger units of an otherwise coarse rock. The problem, then, of the mineral separation under these conditions requires, first, that the rock be ground up or reduced in size until the individual particles comprising the powder are discrete grains, free from impurities consisting of other, associated, component minerals of the rock. An ideal artificial division would afford complete disjunction of all particles from included or adhering mineral particles of other species, but a practical limit is reached in the artificial reduction in the size of grain beyond which it is not desirable to go.

Added to this is the extreme difficulty of handling very fine powder, and the disadvantage of time consumed in so doing. Also a source of error other than that due to impurity of individual particles creeps in if a quantitative separation is sought, namely, the loss of a small portion of the powder during each operation. It is necessary, therefore, to strike a balance between the loss of accuracy due to handling and the loss of accuracy due to the heterogeneity of some particles.

Under ideal conditions all the particles would be of the same size to avoid the introduction of an additional variable. A preliminary size selection being inadvisable—since it would reduce the accuracy of the final results—even a close approach to these ideal conditions seems impossible. However, to some extent at least, the difficulty can be overcome by a suitable selective action satisfying the requirements mentioned in the next paragraph.

The problem requires, secondly, that some method be devised whereby the different mineral particles may be selectively affected, preferably in a mechanical way. It is desirable also that the selective action be based very largely upon definite mineral characteristics which reflect chemical composition or mineral species, and that the action, so far as possible, be independent of variables which are controlled with difficulty, such as, for instance, differences in size and shape of grain and in specific gravity where this is not used as a basis for the selective action. Further, it is essential that the medium

through which the selective effect is obtained does not produce any permanent effect on the physical or chemical character of the mineral substance which may not be recognized as such in further study of the mineral. The selective influence should be easily controlled in order to be of practical value.

Assuming that the desired degree of artificial division of a sample has been reached and that a suitable selective effect has been discovered, the problem requires, thirdly, that the force of adhesion in the powder be overcome. The particles composing the powder do not adhere so strongly after having been ground as they did before, but even as a dry powder they are held together by a force which is relatively very great. The effectiveness of this force increases with the decrease in size of the particles in contact, between which it is acting; it is necessary, therefore, to apply a force proportionately greater in order to separate the particles and to permit any selective action to become effective. Since the proposed separation is to be a mechanical one, the force employed to overcome that of adhesion should cease to operate as soon as it has functioned, in order that the force serving to produce the selective action may operate unhindered or uninfluenced. Failing this, steps must be taken to reduce or control the unselective force before the powder comes under the influence of the force which is selective.

STATEMENT OF RESULTS.

Since it was not known in advance which of the foregoing requirements of the problem would prove the most difficult to satisfy and therefore the most likely to detract from the value of a procedure, each was considered in logical order as outlined above.

Grinding. Rough grinding is a simple process and it can be done in many ways. One of the most convenient methods employs the mechanical mortar. Final grinding for these experiments was done with a hand-operated agate mortar. The reduction in the size of grain is quite rapid at first with brittle minerals but is much less rapid as the particles become small. It was found highly expedient to treat micas first in a diamond mortar, after which they could be much more rapidly ground in an agate mortar. The reduction in size of grain does not, of course, progress uniformly; some of the particles approaching colloidal material in size while some remain too coarse to be

used. It has been stated that a preliminary size-selection of material is undesirable, but that the particles should be of a size as nearly uniform as possible. In order to accomplish this the powder was allowed to settle in water for a certain length of time; that which settled before a certain time was assumed to be too coarse and was reground; that which settled after a certain time was discarded as being negligible in amount and too fine to be used. In this way material was obtained of fairly uniform size, within certain limits. If it is desired to bring these limits closer together more care may be taken in grinding and less time allowed for the settling of the powder used. The procedure outlined below is considered by the writer as satisfactory with regard to the accuracy of the results and the time consumed. A second small source of error has crept in through the rejection of that part of the ground-up powder which remained in suspension in water.

Selective Action. A selective mechanical action, called here the radiometer effect, was found which makes it possible to move certain mineral species selectively, by a projected beam of light, when in powdered form and supported by only a small gas pressure. A commendable feature of the radiometer effect is the fact that it increases in relative intensity with the decrease in size of the particles composing the powder, though there is probably a limit to this increase which has not yet been noticed. The mineral characteristics upon which the effect is believed to be mainly based are color and heat conductivity and probably to a less extent luster. The importance of color is strongly emphasized by the fact that the action has not been developed yet to a satisfactory degree for the white or very light colored minerals. Since the effect increases in intensity with decrease of size of grain, and since there is a range of size of grain present, the effect is variable in intensity; but by eliminating the coarser material, an effect may be produced which is of satisfactory intensity or greater, and the inconvenience caused by this variable is largely overcome. Minerals having a strong platy habit, such as the micas, introduce a difficulty which is not easily appreciated, and one which cannot be readily overcome. The attitude of these particles must undoubtedly be of importance in both sizing by water settling and in their reaction to the radiometer effect. Care was taken to grind these minerals thoroughly in the hope that by this means the difficulty would be obviated to some extent. The

results obtained with micas after taking these precautions appeared to be satisfactorily consistent. The only known effect of the radiometer treatment on the physical characteristics of a mineral is a little gentle heating; no known permanent effect whatever is produced. Control of the radiometer action lies merely in control of the gas pressure at a few millimeters to a fraction of a millimeter pressure.

Adhesion within the Powder. Adhesion of the powdered mineral particles has not been satisfactorily overcome at the gas pressures which are suitable for the radiometer action. Material slightly coarser than that which has been used in these experiments can be successfully loosened by introducing a baffle plate in the course of the falling powder. The deflection of the powder from the vertical, produced by this baffle plate, can be stopped before the powder enters the path of the light by means of a vertical baffle plate placed in a suitable position.

The particles of very fine powder adhere strongly to each other and cannot be loosened by baffling. An attempt was made, therefore, to charge the particles and to induce thereby a mutual repulsion between them, similar in principle but not identical to that employed in the electrostatic separation of coarser materials by virtue of their differences in electrical conductivity. At some gas pressures other than those at which the radiometer effect is operative the powder can be broken up into an extremely fine spray of the most desirable sort; but the conductivity of the gases due to ionization by the electric charge at other pressures has rendered it impossible thus far to loosen the powder by this means.

Adopted Methods of Separation. Heavy solution separation is effective, especially on coarser materials. It fails on very fine materials for the same reason that all such methods fail—adhesion of grains. The details of heavy solution separation are well known and need not be discussed.

Magnetic separation yields from those rocks to which it is applicable, results which are quite similar to those obtained through a heavy solution separation. It is successful with coarse-grained rocks but much less so with those of fine grain and for the same reason—adhesion. In addition to the adhering coat of foreign material on each grain there is the powerful mutual magnetic attraction of all iron-bearing minerals in a field.

The electrostatic separation is based upon the relative electrical conductivity of minerals. Mixtures of minerals, suitably fine according to the coarseness of the rock, are dropped upon a charged inclined plate or a roll; those minerals with the higher electrical conductivity rapidly become charged and are repelled from the plate vigorously; those of low conductivity drop nearly vertically from the plate. In applying this to the common fine-grained rocks there are two apparent reasons that it should not operate. The conductivity of the silicate minerals differs between species much less than that between silicates and sulphides, for example. Air resistance is much more effective in preventing the operation of this process if the rock is finely powdered because of the increased ratio between surface and mass. It is possible that by reducing the gas pressure in a closed system to a small fraction of a millimeter—for above this pressure the gas would be ionized—advantage may be taken of small differences in conductivity.

Bulk flotation depends upon the selective wetting power of minerals by liquids. The methods to be employed in experimentation must necessarily be entirely empirical but with persistence they are very likely to yield satisfactory results. Some of the difficulties encountered and objections to this method may be enumerated. Two phase liquids are not common. Three phase liquids are rare. There is a strong tendency for some two phase liquids to emulsify readily and to settle very slowly; this tendency is sometimes aided by the presence of a mineral powder which surrounds a globule and preserves it—apparently adhering to the interface. Many liquids which wet a mineral selectively do not wet it quantitatively. Many of these liquids, as is true of heavy solutions, are difficultly removable from the separated mineral.

GAS PRESSURE DEVELOPED BY LIGHT.

It has been stated that a method was sought which is based on principles more or less new in their application to this problem. Color and heat conductivity are probably the two outstanding physical properties of minerals which have not been exploited in mineral separation; these were studied to learn what mechanical effect light might produce through them.

Previous work. The radiometer is an instrument which rotates when properly illuminated. It consists (Fig. 1) of two or more vanes in vertical position supported by one or

- more horizontal cross arms which rotate on a vertical axis passing through the center of the cross arms. The vanes are silvered on one side and dark on the other, and they face similarly with respect to the central axis. The whole is in a closed system and is evacuated to about one millimeter gas pressure. When light falls on the faces of the vanes the cross arms rotate about the central axis, in a direction such that the silvered side of the vanes moves toward the light and the dark

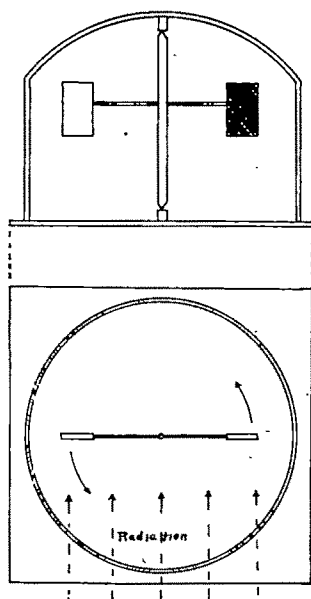


Fig. 1. Radiometer.

side away from it. The accepted physical explanation is briefly as follows: Since the gas pressure is low and since the axis is sharply pointed at both ends, the friction of rotation is at a minimum. However, there is some gas present and it is to this gas that the immediate cause of rotation is to be attributed. When light is allowed to fall upon the vanes of a radiometer, those vanes become heated which have the dark side—the one able to absorb the light rays—toward the light. The heated vane in turn raises the temperature of the gas immediately in contact with it and the gas molecules bombard the vane more vigorously. The thickness of the vane prevents

the heat from traveling through to the other side rapidly enough to cause an equally vigorous bombardment there, with the result that there is a force acting on the vane in one direction. At the other end of the horizontal axis the light, lustrous side of the vane is toward the source of light, and since this reflects the light there is no comparable force in the reverse direction—the axis is rotated. If the pressure of the gas is too low the bombardment is of course weakened and the effect is reduced in intensity. If the pressure of the gas is too high the effect also disappears, possibly due in part to increased resistance to the movement of the vanes but largely due to the mutual interference preventing free movement of the gas molecules. This instrument is described in many texts on physics and no acknowledgment need be made for the above explanation of its action which suggested to the writer that gas pressure might be used to affect mineral particles selectively.

E. F. Nichols and G. F. Hull¹ performed an experiment in which the pressure due to radiation (light pressure) was used to deflect particles of low specific gravity. In so far as gas pressure played a part in the deflection obtained the experiment may be mentioned here. Puffballs of the genus *Lycoperdon* were calcined at red heat to remove the contained oil. The resulting specific gravity was calculated to be not more than .15. These were mixed with emery sand in an evacuated vessel shaped somewhat like an hourglass. The gas pressure is described as being well below 0.0005 mm. The mixed powder was then caused to fall through a beam of light and it was separated into two streams of powder—the emery sand falling straight down and the charred puffballs being deflected by the light. The deflection was attributed largely to the force of light pressure, but it is admitted that gas pressure probably played an important part.

The radiometer and the experiment just described illustrate the conversion of light energy first into gas pressure and then into movement of substances. The same principles may be applied to minerals with a view to learning whether all minerals react equally or whether they are selectively responsive.

¹ Nichols, E. F., and Hull, G. F., The pressure due to radiation: Smithsonian Institution, Ann. Rept., 1903, p. 135.

EXPERIMENTAL DEFLECTION OF MINERALS BY LIGHT.

Deflection of Limonite. If powdered limonite is dropped through a focused beam of a carbon arc light in an atmosphere of air and at suitably low pressures the powder is deflected from its downward path and moves in the direction of propagation of the light. There is a range of gas pressures through which this deflection will take place, but beyond these pressures, either above or below them, no effect is noticed. The range is dependent on the conditions of the experiment, that is, on the degree of division of the particles, on the degree of aggregation of the particles, on the intensity of the light and probably also to a less extent on the shapes of the particles. The curve of intensity of the deflection is not sharp; it is very low at both ends and increases to a peak at about .8-1.0 mm. of gas pressure. Toward each end of the pressure range through which limonite is affected the deflection dies out, not merely by a decrease in the general intensity of the movement, but by the total absence of noticeable deflection of the larger particles, while the small ones are deflected as at more favorable gas pressures. Gradually the amount of powder that is deflected decreases together with the decrease in intensity of deflection. The whole range of gas pressure over which the decrease in deflection takes place from a quantitative deflection to practically none covers about five millimeters at the higher pressures and a little over one-tenth of a millimeter at the lower end. The amount of deflection of the main mass of the powder in the vicinity of one millimeter gas pressure is, for limonite, about one to two centimeters, with a five ampere arc. A twenty ampere arc is now being used with much more vigorous results. Some particles, presumably those very small ones which do not adhering to larger particles or to an aggregate of small ones, are projected along the beam vigorously for the length of the container—about three inches; while doing so they can be seen to rotate rapidly.

Theory of the Deflection of Limonite. There are three forces which might play a part in producing the observed effect of light on the mineral powder; they are, the force of light pressure, that due to a photo-electric effect, and that known to cause the radiometer effect.

Light was regarded for many years by the physicists as having velocity but no momentum. Though the physicists themselves do not entirely agree on this matter at present, it

is rather generally conceded by them that the phenomenon of light pressure is best explained as being due to the momentum of light. The magnitude of this force is, however, exceedingly small, and it is entirely possible that it can be disregarded in this application for practical purposes. To the extent that it is effective it assists in producing the deflection. Light pressure may be more directly responsible for the exceptionally vigorous deflection of the very minute particles.

There is only a possibility that a photo-electric effect may be active, and although it is not clear how this effect, if present, could express itself as a deflection of a stream of falling powder, nevertheless, it seemed advisable to obtain definite information, since it is known that a carbon arc gives off a large amount of ultra violet. Light of short wave length, about 3,000 angstrom units and less, ionizes substances by freeing electrons. The electrons being negative and the nucleus positive, this ionization leaves a substance with a positive charge. The photo-electric effect does not commence at any definite wave length but increases gradually as the wave length of the light used is shortened from about 3,000 angstroms. Ordinary glass such as that used in focusing the arc in the experiment, and the glass plate covering the open end of the apparatus, does not transmit ultra violet light, having a wave length of about 2,900 angstroms or less. The actual limiting wave length is, of course, a function of the particular piece of glass used. A filter screen which does not transmit any light of wave length less than 5,000 angstroms was placed between the lens in front of the arc and the glass plate covering the open end of the apparatus. Some limonite powder was dropped through the beam and was deflected with vigor apparently equal to that of the deflection when the ray filter was not used. This was regarded as conclusive proof that the photo-electric effect was absent or only negligibly present as a factor in the force which produced the deflection.

Light of long wave length, that is, infra red rays, having a wave length of about 10,000-20,000 angstroms, is comparable to and a gradation into heat waves, and the effect which these rays produce on a substance on which they are incident is similar to the effect of heat waves. Since infra red rays are transmitted with difficulty through water, a layer of water about one and one-half inches thick was placed in the system in the same position that the yellow filter (5,000 angstroms) had previously occupied. On dropping some limonite powder

- through the beam from which a large part of the infra red rays had been removed the deflection was very slight. It seems to be reasonably certain, then, that the infra red rays are mainly responsible for the deflection of the stream of powder.
- The explanation must be almost identical with that for the rotation of the radiometer vanes. The light strikes the individual particles or aggregates and by warming them warms the gas in contact with them. This gas then produces gas pressure on the side of the particles toward the light and repels them. Since the particles can be seen to rotate rapidly while being propelled, it is necessary to assume if the particle itself is heated, that it is heated (above normal) only surficially and that it loses its surficial heat on the side away from the light almost as soon as that side is no longer exposed to the light. Since, as mentioned below, the color of the solid is such an important factor in the operation of the radiometer effect, the particle itself and not merely the gas film around it plays some part in causing the gas pressure. But the rapidity with which the gas pressure ceases to act when the particle turns over, indicates that the heating of the particle is of the most surficial sort, for it could not otherwise lose its heat so readily. The following explanation is therefore offered to account for the observed phenomenon accompanying the deflection of a mineral powder.

The atoms at the surface of a crystal are definitely arranged with respect to each other in a plane lattice formation, but they have only a part of their valences satisfied. According to Dushman,² "The space between and immediately above these atoms is surrounded by a field of electro-magnetic force more intense than that between the atoms inside the crystal." The persistent adsorption of gases at the surface of a solid even at low gas pressures has been explained on this basis. Evaporation and condensation of gas molecules is going on as a continuous process, evaporation increasing with increase of temperature. Quoting again from Dushman, "Adsorption is a direct consequence of the time lag between condensation and evaporation." And again in referring to finely divided material, "Bancroft mentions a number of cases in which very

²For a concise discussion of this subject with references see Dushman, S., *High Vacuum*, p. 207. General Electric Review, 1922.

Key
 v = vigorous
 s = suitable
 q = quantitative
 m = marked
 sl = slight
 f = faint

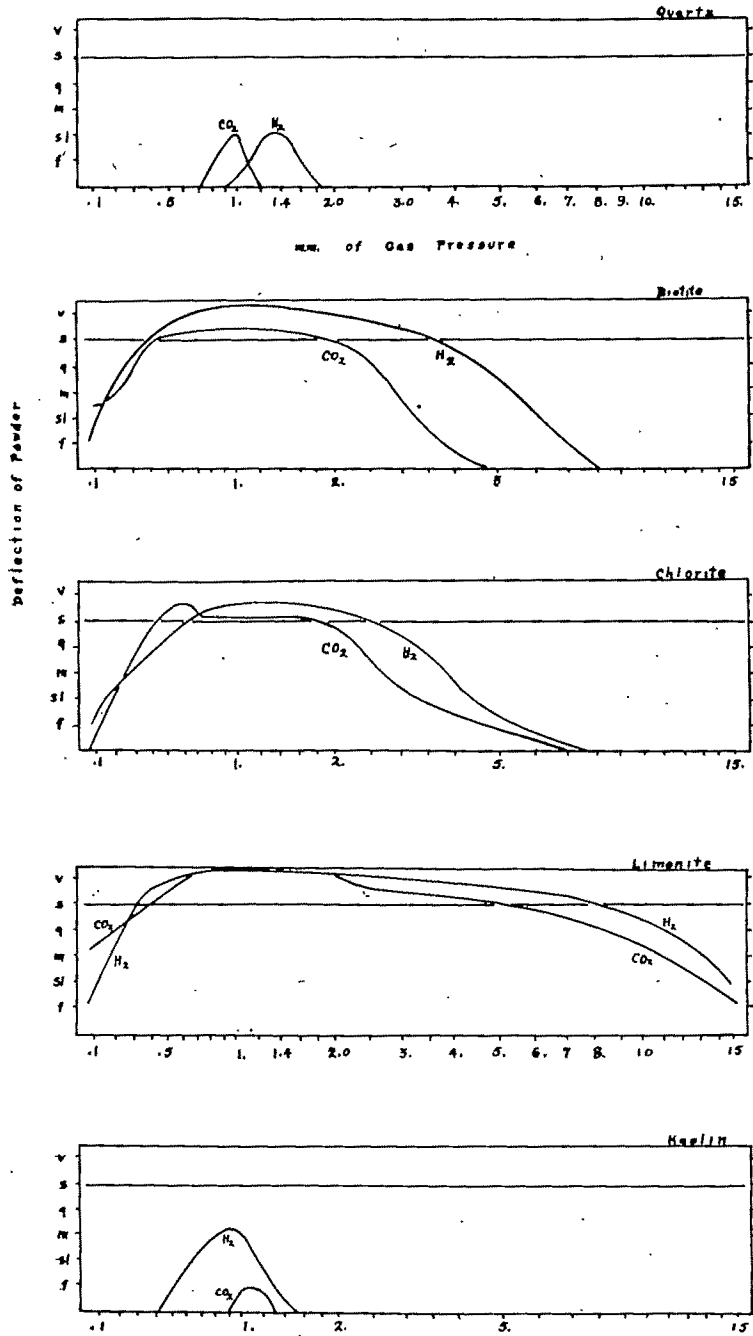


Fig. 2. Radiometer Deflection Curve of Certain Minerals.

- fine powders apparently have appreciable films of air or other gases surrounding each small particle." It may be accepted,

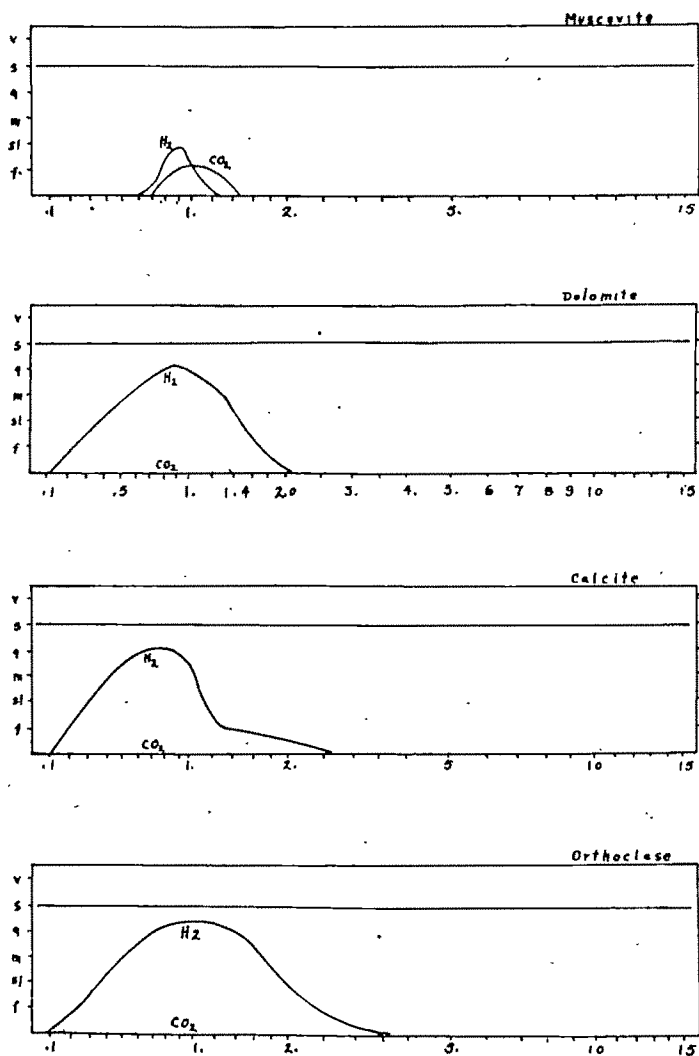


Fig. 2. Continued.

therefore, that each particle of the limonite powder has an adsorbed film of air around it and that the molecules composing this film are being continually replaced by others.

through the process of evaporation and condensation described above. Further, the equilibrium between evaporation and condensation is very flexible and is particularly responsive to changes of temperature such, for instance, as those produced by light radiation. Accordingly, it is quite conceivable that the heat absorbed does not reach beyond the surface layer of the solid substance but mainly affects the adsorbed film of air, causing a sudden increase in evaporation of gas molecules and consequent increase in gas pressure on that side, to be followed on the rotation of the particle—so that the formerly exposed part of the gas film is shielded from the light by the particle itself—by an equally sudden increase in condensation over evaporation and perhaps even by a corresponding but faint momentary decrease in gas pressure.

Deflection of Other Minerals. The effective range of gas pressures is different for different minerals and appears to be in general characteristic of the species of each individual mineral subjected to the experiment. The members of those mineral species whose chemical composition, and, therefore, whose physical properties, notably their color, vary have a range which is not the same for all members of the species. White or light colored minerals, under the conditions of these experiments, reacted but feebly to light.

Tests were made with three different gases, air, carbon dioxide, and hydrogen; all of them were desiccated by passing them through concentrated sulphuric acid or over phosphorous pentoxide. Carbon dioxide and air give curves of the reaction to light which are, for the purposes of these experiments, practically identical, but hydrogen gives curves which are different, though the differences are not very great. To the extent that hydrogen does give different curves the difference is in extending the range and in increasing the intensity of the reaction. The peaks of all curves are essentially in the same place. Fig. 2 gives the curves worked out for carbon dioxide and hydrogen on nine minerals, plotted in a degree of detail consistent with the degree of grinding and sizing of the material and mutual freeing of the particles composing the powder. The scale on which the millimeters of gas pressure are plotted is logarithmic to conform to the logarithmic scale on the McLeod vacuum gauge, and it also brings out more clearly the rapid changes in the radiometer effect at the lower pressures.

Limonite, chlorite and biotite respond most vigorously, of the minerals, to the light effect. Magnetite and graphite, which

were not studied in equal detail and are not plotted, have very similar curves. The other minerals respond weakly or not at all in air and carbon dioxide but respond much better in an atmosphere of hydrogen. It is to be remembered that these curves are true only for the conditions of the experiment outlined in the procedure described below.

The Use of a Static Charge. It has been mentioned that the selective radiometer effect on minerals is not completely operative in very intimate mixtures of mineral powder because of the adhesion of the particles.

Two bodies similarly charged repel one other. If it were possible, therefore, to charge the individual particles of the

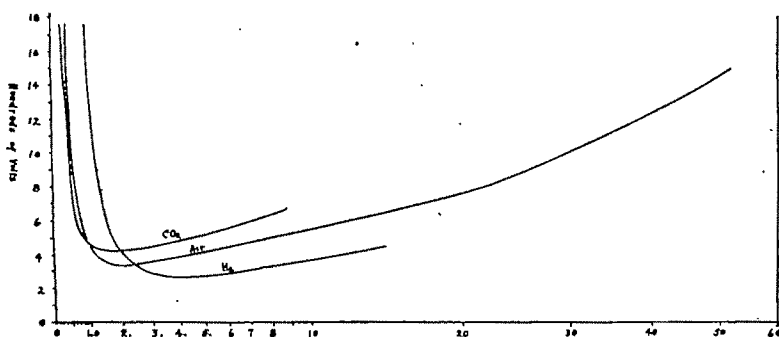


Fig. 3. Sparking potentials at low gas pressures—3 mm. spark gap. Curves plotted from data given in "Electricity in Gases," J. S. Townsend, 1915, p. 361.

mineral powder to such an extent that the force of mutual repulsion exceeded that of adhesion, then it would be also possible for the selective radiometer effect to operate. The principle of the mutual repulsion of bodies similarly charged is taken advantage of commercially for a very similar purpose in the electrostatic separation of minerals already mentioned. It is necessary, however, to overcome the force of adhesion at the gas pressures at which the radiometer effect can be obtained, but as suggested above in another connection, the conductivity of gases at these pressures is relatively great, due to the ease with which the gases may be ionized. The baffle plate cannot be strongly charged, and even if a charge could be imparted to the powder it would be immediately conducted away. A study of the accompanying sample conductivity curve (Fig. 3) will illustrate the difficulty. It was found empirically that it

is necessary to descend to air pressures of .002-.001 mm. before a suitable charge can be imparted to the powder used. These figures indicate the upper limit of gas pressure. At the other end of the radiometer pressure range there is a difference of several centimeters of gas pressure between the highest pressure at which the radiometer effect is operative and the lowest at which the powder can be suitably charged. In other words, it seems that only the lower end of the radiometer range can be used if the electrostatic charge is to be applied. This obstacle in the application of the radiometer effect has thus far proved insurmountable, but, as pointed out below, there are still possibilities.

PROCEDURE.

During the time in which the several hundred readings were made, four hundred and fifty-five of which are represented in the curves of Fig. 2, the procedure was condensed as much as possible and may be briefly outlined.

Preparation of Powder. Most minerals were powdered first in a diamond mortar and afterward in an agate mortar; all were finally ground in an agate mortar. It is of course impossible to grind all the material evenly to a suitable degree of fineness and in order to separate the coarse from the fine for regrinding, the powder was roughly sized by allowing it to settle in water. To do this the powder was mixed with some distilled water in a test tube and shaken, then poured into a 250 cc. beaker and enough distilled water added to make it 2 cm. deep. This was allowed to settle for ten minutes, after which the water and suspended powder was poured off into another 250 cc. beaker, where it was allowed to settle for forty minutes. The powder which had settled in ten minutes was dried and reground; that which settled for forty minutes was dried in a watch glass on a hot plate by warming it gently. The water and suspended powder which was poured off after standing for forty minutes was discarded. Only a very small amount of the powder can be prepared at a time. This procedure can be modified considerably with quite satisfactory results.

Manipulation of Powder. The powder was then placed in the apparatus and the opening was sealed by a glass plate. The powder rests on an inverted cone of glazed paper placed above the baffle plate in such a way that a slight vibration causes it

- to drop in a slow stream on the baffle plate. The baffle plate being inclined, the powder glances off against a vertical plate and drops almost vertically down through a beam of light. After placing the powder in the apparatus and sealing the open end, the system was exhausted to about .1 mm., then flooded through the desiccator with air (or carbon dioxide or hydrogen if either of these gases was being used) to about 60 cm., allowed to stand for about ten minutes and exhausted to .01 mm. In this way part of the moisture vapor which has access to the system while it is open may be removed and conditions made more constant. After securing the desired gas pressure the light was turned on and the powder was made to drop through the beam. A steady and uniform stream of powder may be obtained conveniently by applying an A. C. vibrator to any solid part of the apparatus. Gas was introduced in controlled quantities and readings were made after each small change of gas pressure. The deflection is described as quantitative when all of the powder is visibly deflected but some of it only weakly so; it is described as suitable when all of the powder has been deflected an amount that would afford a convenient means of separating the powder deflected from one that had dropped without deflection.

DESCRIPTION OF APPARATUS.

The apparatus consists of two main parts—that in which the mineral powders were treated, called here for purposes of reference the vessel, and the remainder which served to obtain and control conditions in the vessel. The essential parts of the control apparatus are; the pumps, the gauge, the desiccator, the inlet valve, the mercury stop valves, and the gas generator.

Exhaustion Pump. A cenco Hyvac rotary oil pump was used in these experiments. It will conveniently exhaust a properly constructed system to .001 mm. and if it is desired to carry on experiments of the sort at still lower pressures, this pump serves as an excellent backing pump for a mercury vapor pump. Care must be taken not to allow mercury from the system to enter the pump. Also, since the pump is oil sealed, gases which are soluble in the oil or may have a deleterious effect upon it cannot be allowed to pass through the pump.

Mercury Vapor Pump. For pressures in the vicinity of .001 mm. of mercury it is desirable to use a mercury vapor pump. For pressures below this it is essential. Fig. 5 illus-

trates this style of pump. A flask of mercury is heated and the vapors generated are directed down a tube in the direction in which it is wished to have the gas flow. The process of simple bombardment of heavy vapor moves the molecules of the gas being evacuated. The mercury vapor is condensed in a large bulb and returned to the heated flask. Such a pump is capable of producing a difference of pressure equal to .002.

When working at pressures as low as .001 it is desirable to have in the system a mercury liquid air trap. The mercury vapor is then frozen at that point and cannot move beyond it. Such a trap is placed before the mercury vapor pump, thereby shutting off all mercury vapor from that part of the system in which the experiment is being conducted.

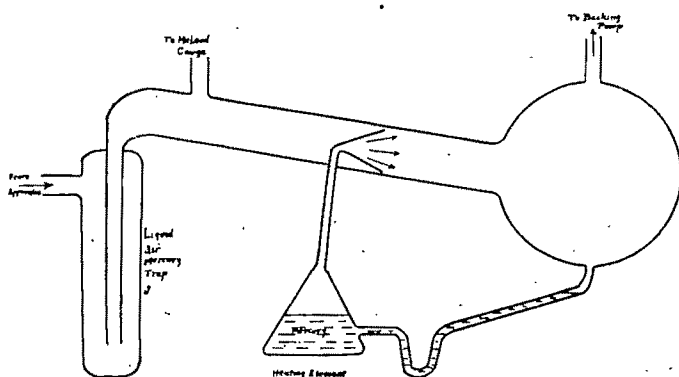


Fig. 5. Langmuir Mercury Condensation Pump.

"Vacuum" Gauge. The gauge used here is of the standard McLeod gauge type diagrammed in Fig. 6. The principle of this gauge is that a certain volume of gas (the bulb A) at the pressure prevailing through the system of which the gauge is a part, is compressed in the tube above the bulb A under a head of mercury equal to the distance between the top of this tube and the position of the top of the mercury column within it. This head is obtained and the reading made by raising the mercury reservoir, B, which is open to the air, and thereby raising the mercury column in the tube C till it stands in the tube D at the elevation of the top of the tube above the bulb A. Two convenient modifications of the gauge, seldom described, are of interest for the purpose of experiments of this sort. The tube above the bulb A along which the scale is read may

well be made of capillary tubing at the top and of larger tubing—about 3/16 inch for a bulb of 50 cc. capacity—between the capillary and the bulb. The range of pressures through which one is able to make readings is thereby materially increased. Readings may be made much more conveniently if the reservoir is attached directly to the bottom of the gauge proper by heavy rubber tubing and is not open to atmospheric pressure but is also under vacuum. The level of the mercury in the reservoir is, then, always approximately at the level of the mercury in the gauge.

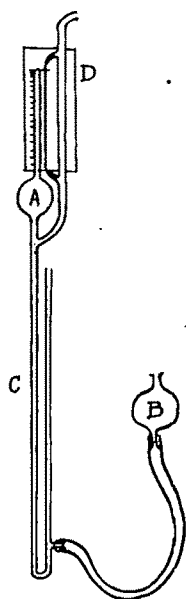


Fig. 6. McLeod Gauge.

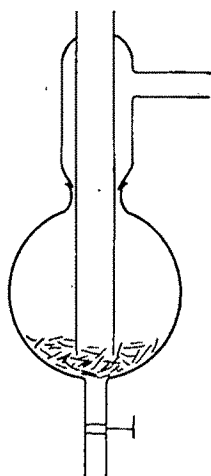


Fig. 7. Desiccator.

Desiccator. The desiccator serves to bring all gases which pass through the system into intimate contact with a dehydrating agent. The form finally adopted as the most convenient is illustrated in Fig. 7. The dehydrating agent used—phosphorous pentoxide—is distributed through glass wool, through which the gases must pass either way. In the bottom of the desiccator is placed an inlet to the entire system, thereby drying all gases coming in as well as those going from the system to the pump. The desiccator also serves as an emergency

mercury trap. The lower part of the desiccator is detachable to permit replenishing of the desiccating agent; it is sealed to the upper part by wax.

Inlet Valve. When making a series of readings it is necessary to move up the pressure scale by small increments of known amount. To do this a valve was devised whereby any small amount of a gas may be admitted to the system (Fig. 8).

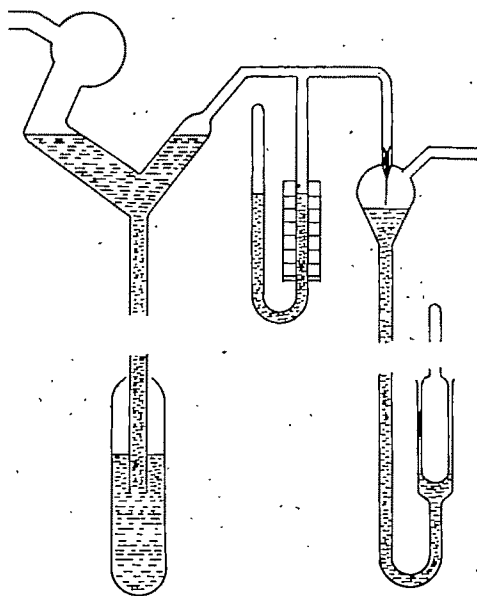


Fig. 8. Mercury Stop Valve Manometer Gauge and Inlet Valve.

It consists of a capillary tube drawn down, dipping into mercury. To open the valve the level of the mercury is lowered and to close it the mercury is raised. To accomplish the change in the mercury level most conveniently a glass plunger on the end of a glass rod is raised and lowered in a mercury reservoir connected with the mercury into which the capillary tube dips. It was found that a capillary tube drawn down to an exceedingly fine opening will take in mercury under a difference in head of 76 cm. The opening was increased to a suitable size and placed in a closed system at a difference in head such that the mercury will not force its way in, but gas enters fairly readily. The closed system was kept at a gas pressure of about 15 cm.; it receives its gas from the desicca-

tor. The capillary tubing does not lead directly into the main system but into a small subsidiary one fitted with a mercury filled U-tube and scale graduated in fractions of a millimeter in terms of the entire system.

To make the capillary tubing of the proper size the following method was employed to advantage. Heat a piece of capillary tubing in a small flame till the center closes. Draw it slightly so that the closed part will cool first. When this part has cooled below red heat draw rapidly and strongly. The short cone-like opening at each end of the closed part is thereby elongated, but when broken off at the proper place there is not left a long frail glass rod to work with as is otherwise the case. This drawn-out tube is sealed in with wax.

Mercury Stop-Valves. Stop-cocks leak sooner or later. When freshly greased they do not leak provided they are well ground, but one is never able to search satisfactorily for a leak in a system in which there are stop-cocks. A stop-cock is entirely unsatisfactory for a valve which is to be opened and closed frequently. A very simple and well known valve which can be used where the difference in head of mercury is not over a few centimeters was used for a secure seal in this apparatus. It consists merely in stopping the bottom of a U-tube with mercury. This type of valve may be used to great advantage in conjunction with a stop-cock (which may leak slightly) as is illustrated in this system (Fig. 8). To open or close a valve of this sort the level of the mercury reservoir connected is changed. In case the difference in head becomes great enough to cause a movement of gas from one side of the U-tube to the other a mercury trap is necessary such as that illustrated in the figure to prevent the mercury from going through the system.

Gas Generator. The gas generator used is a quite simple standard one described in elementary chemistry text books. It includes a gas reservoir to make possible sudden drains on the supply. Tanks of compressed gas are still better.

All joints are welded glass or sealed with sealing wax or "half-and-half." There is no rubber tubing within the system. The few emergency stop-cocks in the system are waxed up. The desiccator is so placed that all gases moving either into the system or from the system to the pump may be made to pass through it. The desiccator may, however, be cut out entirely and, in fact, most of the final evacuation was done without it.

The Vessel. The vessel (Fig. 4) is cylindrical, open at one end and has an outlet tube welded to the side and leading to the rest of the system. The cylinder lies horizontally, allowing the plate which covers the open end to stand vertically. On top is a half inch tube in which the mineral powder is placed. This tube is open at the top to facilitate introduction of the powder, and it is closed by means of a ground glass stopper waxed in place. The powder is introduced on a funnel-shaped piece of glazed paper supported on a wire ring by which it can be readily handled. The powder when falling is confined to a small glass tube till it is near to the baffle plate. The baffle plate is made of aluminum, and has a smooth surface; it is

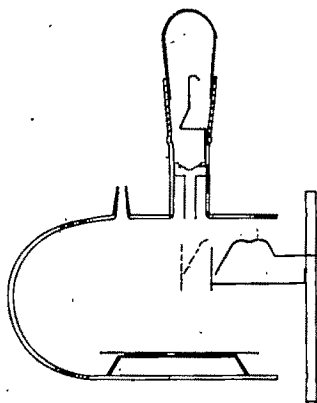


Fig. 4. The Vessel.

riveted to a copper wire as a support, the wire leading outside through the glass plate. The vertical baffle plate is made of glass; it also is supported by a wire attached to the glass plate. The glass plate covering the open end of the apparatus was placed on a horizontally revolving wheel and, using emery powder, the cylinder was ground into it, making a groove. To attach the glass plate to the cylinder previous to evacuation this groove is filled with wax, the wax heated by a hot circular wire fitting the groove and the groove is then made to fit tightly over the end of the cylinder. The glass-wire joints are made with wax.

Light. A 90° carbon arc was used as a source of light, operated on 110 v., 5 amp., D. C. A short focus lens was used to concentrate the light, the distance between the carbons

and the vertical baffle plate being about twelve inches. In later experiments a 20 ampere A. C. arc was used.

Static Machine. While attempting to charge the mineral powder a motor-driven static machine giving a quarter-inch spark was connected by one terminal to the inclined baffle plate by means of the wire support leading outside, and by the other terminal to a platinum wire welded through the wall of the exhaust tube of the vessel.

RECAPITULATION.

These experiments were carried out with the purpose of finding a new and more effective means of separating minerals, especially when in fine-grained mixtures. They offer a new selective means of moving minerals mechanically. When applied to mixtures the selective force is hindered from operating perfectly by adhesion between grains of different mineral species. This unfavorable influence becomes progressively stronger with reduction in grain size.

If some means can be found to overcome the force of adhesion under these circumstances then the writer feels that a highly satisfactory means of mineral separation will be available. It is in the hope that someone else may succeed in this particular that these results are offered.

The outstanding objection to the use of the method is the necessity of working with a vacuum which entails considerable apparatus and some knowledge of glass blowing and vacuum technique.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge his indebtedness to other members of the geology department at Madison and to Professors Max Mason and J. A. Eldridge formerly of the Physics Department. The experiments were carried out in the geological laboratories of the University of Wisconsin.

UNIVERSITY OF WISCONSIN,
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AN OCCURRENCE OF ORISKANY SANDSTONE WITH CELESTITE CEMENT.

MARCELLUS H. STOW.

In the course of a petrographic study of Oriskany sandstones in Western New York, an interesting occurrence was noted at Phelps, Ontario County, where the intergranular substance proved to be celestite. From consideration of the literature it seems that celestite is not uncommon in limestones, though it has rarely been found in sandstones. Moreover, its known presence in the overlying limestones suggested that this locality might furnish some suggestion as to conditions of sedimentation and induration.

Without discussing at length the problem of Oriskany sedimentation, it may not be amiss to record a few observations bearing on that subject as a sort of background for the more special celestite investigation. Between Honeoye Falls to the westward and Oriskany Falls, over which distance practically all known outcrops were examined by the writer, the sandstone has an observed thickness of not more than twenty feet, and at several places is entirely absent. In addition to the breaks in continuity recorded on the Geologic Map of New York State (Merrill, 1901), two localities were observed, one at Shortsville and one at Mertensia, where the overlying and underlying limestones were identified without the characteristic Oriskany between them. Even in the small area at Phelps, thicknesses varying from about three feet to only a few inches were seen. Specimen 203, from the bottom of a three foot section, consists of roughly conical sandstone masses about an inch long by half an inch in diameter extending down into the Manlius limestone. These cones may on further study furnish significant evidence as to the conditions of sedimentation under which the Oriskany was laid down. The presence of a few hypersthene grains (in the more easterly exposures) is another observation which is held for consideration as to its bearing on the direction of transportation, since hypersthene is abundant in some rocks of the Adirondacks.

At Phelps the Oriskany outcrops in the valley of Flint Creek southwest of the town. Twelve specimens were collected representing the sandstone from an area about three hundred feet long by one hundred feet wide, bisected by the stream. The locations of these in detail are recorded in the

manuscript of a thesis by the writer deposited in the library of Cornell University.

Specimens 1, 2, and 3, representing a vertical section near a small waterfall, are light gray in color, even granular, and the sand on the weathered surface can be crumbled off with the fingers. The unweathered material is not so easily crumbled. Specimen 6 was obtained from the bottom of the outcrop about two hundred feet to the eastward. It is dark gray in color and contains some small nodular masses of more firmly cemented sand. In the north wall of the gorge about fifty feet west of the fall, the Oriskany is only a few inches in thickness and is represented by Specimen 7, a dark gray, sandy limestone. Specimens 200, 202, and 203 were taken from the top, middle, and bottom, respectively, of an exposure three feet thick near 1, 2 and 3. The first two of these are light brown, even granular, and are easily crumbled with the pestle. Specimens 208 and 209 are from the top of the exposure between 200 and 211, and occurred about twenty-five feet apart. They are brown, stained slightly with limonite, even granular, and easily crumbled with the pestle. Specimens 211 and 213 were collected from the north wall of the gorge about fifty feet east of 6, the former from the top and the latter from the bottom of the Oriskany formation. The sandstone here is light gray and somewhat stained with limonite; it is even granular and is easily crumbled with the pestle. The induration of these sandstones proved, on laboratory study, to be due to deposition of calcite, quartz, or celestite. The size of the grain is indicated by the fact that an average of 82 per cent of the crushed material is retained by bolting cloth having 96 meshes to the lineal inch and an opening of 0.17 mm., while none of the grains were larger than about 1 mm.

The following laboratory procedure was employed. The specimens of sandstone were first brushed free from adhering organic matter and clay. They were then carefully crushed by means of a pestle and mortar, in an attempt to obtain, as nearly as possible, material of the same grain-shape and grain-size as the original sand. A weighed sample of this material was washed to remove clay and dust, after which it was treated with dilute hydrochloric acid to remove calcite and limonite. Separation of this sand into portions of various grain-sizes was accomplished by sieving through bolting cloth. Heavy minerals were removed from those of low specific gravity in a

separatory funnel by the use of bromoform having a gravity of 2.86. Percentages of each separate were calculated and slides prepared by mounting the grains in Canada balsam.

In some of the slides of mounted grains celestite was found. It was in granular fragments often showing cleavage. With the index liquids available, the index was determined to be between 1.616 and 1.624. A flame test gave the characteristic red of strontium. When present at all in a heavy separate, it averaged about 98 per cent, with a maximum of 99 and a minimum of 96 per cent.

Table I shows the percentage of celestite in the *heavy* separates of each of the samples.

TABLE I.

Specimen ..	1	2	3	6	7	200	202	203	208	209	211	213
% Celestite	98.7	96.5	99.0	0	0	98.6	0	2.0	0	0	97.3	97.0

Three thin-sections were prepared, one each from the bottom, middle, and top of the sandstone.

A study of a thin-section from the bottom of the bed showed rounded to subangular quartz grains. The arrangement of these was very irregular. In one part of the section they were closely compacted with no cement between. In other areas the grains were widely spaced, in some cases almost completely isolated, touching each other at only one or two points. The cementing material was calcite. No celestite was observed in this section, though a specimen obtained only a few inches away yielded about 3 per cent of that mineral when crushed. This would indicate that the distribution of the celestite is very uneven.

A thin-section of the sandstone from the middle of the formation, one and a half feet above the first, showed the quartz grains to be much more closely compacted. Here again the packing is not even, but the grains are not as widely separated as in the first. In this section the cementing material was mostly calcite, but some celestite cement was observed in disconnected areas. The celestite and calcite were not often in contact; the celestite was the cement in one part of the slide and the calcite in the other, hence the relative time of deposition was not evident.

In the thin-section from the top of the bed or about three feet above the source of the first slide, most of the cement between the grains was celestite. Very little calcite was seen.

Again the celestite and calcite were rarely in contact. However, in one part a small vein of calcite was found extending through a particle of celestite and as stringers between the celestite and quartz. Though the calcite is clearly of later deposition, no definite opinion was formed as to whether the process was one of fissure filling or replacement.

In reviewing the literature on the occurrence of celestite in sedimentary rocks some fifty communications were found, of which those applying most closely to the problem in hand were two articles published in this Journal, one by E. H. Kraus,¹ and the other by E. H. Kraus and W. F. Hunt.² In these two papers the authors show that "the celestite was no doubt deposited simultaneously with the rock material," and that there has been a "solution of celestite in the strata near the surface and deposition in the lower and cavernous beds." Observations of the rocks at Phelps seem to agree with the views of Kraus and Hunt just quoted, the Oriskany serving as the porous or "cavernous" beds for deposition of celestite from the overlying Onondaga limestone.

Table II exhibits the relationship between the amount of celestite in the rocks and their vertical stratigraphic position.

TABLE II.

Specimen ..	1	2	3	6	7	200	202	203	208	209	211	213
Position ...	Bottom	Middle	Top	Bottom	Top Middle Bottom	Top	Middle	Bottom	Top	Top	Top	Bottom
Celestite.	3	5	7.5	0	0	2	0.	2	0	0	2.8	2.8

It will be seen that of the five specimens from the top of the bed, three contain celestite and two do not; of the two from the middle, one contains celestite and one does not; and of the four from the bottom, three contain celestite. It will be noted that in all these the upper layers contain as much or more celestite than those below.

Though by petrographic methods no celestite was found in the associated limestones, a spectrographic examination by Mr. D. A. Holt of the Department of Chemistry at Cornell University indicated about 0.2 per cent of strontium in the

¹ Kraus, E. H., The Occurrence of Celestite near Syracuse, N. Y., and its Relation to the Vermicular Limestones of the Salina Epoch, This Journal, 18, 30-39, 1904.

² Kraus, E. H., and Hunt, W. F., The Occurrence of Sulphur and Celestite at Maybee, Michigan, this Journal, 21, 237-244, 1906.

Onondaga limestone above the sandstone and about 0.02 per cent in the Manlius limestone underlying it.

The "pockety" occurrence of the celestite as a cement in the sandstone would suggest that there was no universal deposition of it.

The writer is inclined to believe that strontium sulphate was deposited as an original, fine-grained, constituent of the Onondaga limestone, and that it was dissolved by downward percolating water and carried into the coarser Oriskany sandstone where porosity gave opportunity for evaporation of the solution with resultant precipitation as a cement between the sand grains. It may be noted that where the total thickness of the Oriskany was only a few inches, specimen 207, no celestite was found.

The much smaller quantity of strontium in the Manlius may have permeated through the Oriskany from the Onondaga, or, as is perhaps as probable, may have been originally deposited here as well.

The writer wishes to express his sincere appreciation of the aid given by members of the Department of Geology at Cornell University where the investigation was conducted.

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DISCUSSION AND COMMUNICATIONS.

HERSCHEL'S VIEW OF ISOSTATIC ADJUSTMENT.

In the May number of this Journal, Dr. Bowie calls attention to certain ideas of Petit, published in 1849, which in part anticipated the conception of isostatic compensation developed by Airy and Pratt. Discussion of early ideas related to this subject calls to mind the names of Herschel and Babbage. These men have been cited together in numerous papers, and there seems to be a rather general belief that they are to be credited jointly with the germ of the isostatic theory. This belief is not confirmed by a study of the literature, as Knopf has pointed out.¹ Sir John Herschel speculated about the consequences of heavy sedimentation, and in a brief, informal statement outlined a theory of the mechanism by which balance may be restored in the lithosphere. This is the idea for which Babbage has been given part credit; but the credit belongs to Herschel alone.

Probably some of the confusion in this matter has resulted from the fact that Herschel's speculation was printed in a book published by Babbage. This book, *The Ninth Bridgewater Treatise*,² is occupied chiefly with arguments in favor of "Natural Religion." It even invokes mathematics in an attempt to establish the probability of miracles. Some of the appendices, however, present matters of purely scientific interest. Among these is a letter written by Herschel to Charles Lyell on February 20, 1836. After some discussion of Lyell's "Geology," he says: "Now for a bit of theory. Has it ever occurred to you to speculate on the probable effect of the transfer of pressure from one part to another of the earth's surface by the degradation of existing and the formation of new continents . . . ?" There follow several pages of reasoning on the behavior of the isogeotherms, and on the formation of volcanoes. Finally, "Laplace's* idea of the elevation of surface due to columnar expansion (which you attribute, in a note, to Babbage,) is in this view inadequate to explain the rise of Scandinavia, or of the Andes, etc. But, in the variation of local pressure due to the transfer of matter by the sea, on the bed of an ocean imperfectly and unequally supported, it seems to me an adequate cause may be found. Let A be Scandinavia, B⁸ the adjacent ocean (the North Sea), C a vast deposit, newly laid on the original bed D of the ocean; E E E a semi-fluid, or mixed mass, on which D D D reposes. What will be the effect of the enormous weight thus added to the bed D D D (rock being heavier

¹ A. Knopf, *Bibliography of Isostasy*. 1924, p. 15.

² Second Edition, London, 1838.

* "Nisi Mitscherlich's. I remember well to have read it somewhere or other."

than sea)? Of course, to depress D under it, and to force it down into the yielding mass E, a portion of which will be driven laterally under the continent A, and upheave it. Lay a weight on a surface of soft clay: you depress it below, and raise it around the weight. If the surface of the clay be dry and hard, it will crack in the change of figure."

There is no direct indication, in this brief discussion by Herschel, that he had any conception of compensation for relief features by differences in rock density. It is evident, however, that he considered the upstanding continental mass to be in equilibrium with the lower ocean basin before sedimentation occurred; and judging from his figure, he conceived that only a partial filling of the basin by sediments might make the oceanic segment much the heavier of the two. It may be inferred, therefore, that he had in mind the principle of compensation. He makes

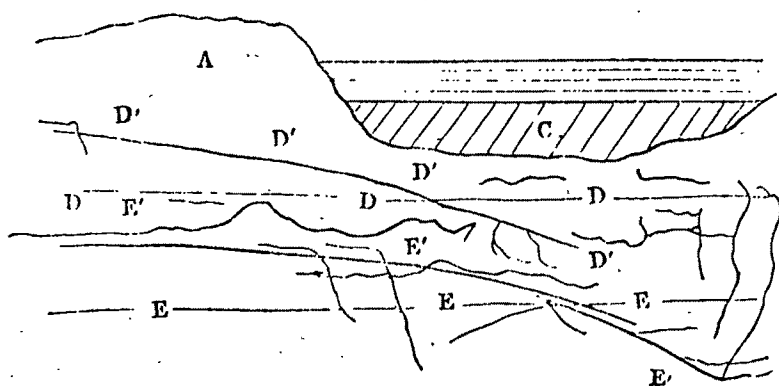


Fig. 1. Herschel's diagram to illustrate adjustment between a basin loaded with sediments and the adjacent continent. (From *The Ninth Bridgewater Treatise*, 2d Edition.)

no direct statement of the depth at which movement for adjustment may occur; but it appears that he conceived of movement in a relatively shallow zone. The transfer is not in a layer of liquid magma. He considers this possibility, but decides that the effect of loading in a crust resting on such a universal *magmaschicht* "would merely be an almost infinitely minute flexure of the strata; but, supposing the layer next below the crust to be partly solid and partly fluid, and composed of a mixture of fixed rocks, liquid lava, and other masses, in various degrees of viscosity and mobility . . ." Thus the general mechanism he proposed, so far as it is outlined in his brief statement, is remarkably like that assumed by some modern students of isostasy.

* The letter B was omitted from Herschel's diagram.

Confusion of Herschel's views with others propounded by Babbage appears to have started with Lyell himself. Herschel tried to correct the error in a letter to Murchison⁴ dated Nov. 15, 1836. He says: "In a letter you allude to as having been written by me to Mr. Lyell, there are some speculations about the effect of central heat on newly-deposited matter, which, judging from some expressions in his answer to that letter, I am inclined to think must have been put obscurely, since he appears disposed to regard the view I took of the subject as identical with some theory ascribed to Mr. Babbage (but, I believe, before propounded by Mitscherlich) about the elevation of strata by *pyrometric expansion* of the subjacent columns of rocks, by an invasion of subterranean heat . . . ; but *this* was not my drift." From further study of Babbage's writings, it is evident that both he and Herschel considered the movement of isogeotherms and the consequent expansion and contraction in the lithosphere. Babbage sought to explain uplift and subsidence by this cause alone. Herschel added the conception of mass balance between adjacent parts of the crust; but his brilliant speculation was premature, and his contemporaries failed to grasp his meaning.

The brief, informal character of Herschel's statement should be kept in mind by those who may be disposed to judge it critically. He was an astronomer, and this incursion into the field of geophysics was only incidental. Criticism is easy, with nothing more than his crude diagram and his short letters to represent his conception. From his mention of the Andes, one may wonder whether he considered the adjustment to erosion and sedimentation a sufficient explanation of all mountains; but it is not likely that he attempted to follow through all the consequences of the mechanism he suggested. In the original letter to Lyell he says: ". . . the stars leave me very little time to lick into form any geological theories, or even to examine them with any degree of scrupulous severity."

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⁴The Ninth Bridgewater Treatise, 2d Edition, pp. 237-240.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

History of the Sheffield Scientific School of Yale University, 1846-1922; by RUSSELL H. CHITTENDEN. Two vols. Pp. x, 610; with photographs and illustrations. New Haven, 1928 (Yale University Press, \$10.00).—No one living is so well fitted to write this history as Professor Chittenden. He has been actively connected with the Scientific School for fifty years, as undergraduate, instructor, professor of physiological chemistry and director. He helped it develop from a small beginning; he organized and carried on a Department of Physiological Chemistry from which an astonishing number of men graduated who have become distinguished investigators and physicians; and he was the able director of the school for twenty-four years.

The two volumes give an accurate, detailed history of the School and the men associated with it, from its beginning as the School of Applied Chemistry of Yale College to the close of Director Chittenden's term of service in 1922. Benjamin Silliman, Jr., and John P. Norton organized the School in 1846. They were pioneers in scientific education in this country and the system of education which they and their successors developed in the first twenty or thirty years of the School's existence served as a model for much of the instruction in science throughout the country. For this reason, Professor Chittenden's History is, in a broad sense, a history of scientific education in America.

There appear to have been two major factors which enabled the School to grow and prosper during these difficult years, with little help from the college. One was the financial help of Joseph E. Sheffield, and the other, the quite extraordinary group of professors associated with the School. The names of nearly everyone of this group appeared so often in the pages of this Journal in those years, as well as later, that we give the list of the men who served as professors in the first twenty years. They were: John P. Norton, Benjamin Silliman, Jr., William A. Norton, John A. Porter, George J. Brush, William H. Brewer, S. W. Johnson, W. D. Whitney, Daniel C. Gilman, O. C. Marsh, A. E. Verrill, D. C. Eaton and James D. Dana. Full credit is given to Brush, who directed the School from 1872 for twenty-six years with immense success. The second volume of the work covers the twenty-four years of Professor Chittenden's directorship.

The last chapter of the book is perhaps the most interesting and important to those concerned with present-day conditions. It has to do with the situation of the Scientific School since 1919, and represents the views of a man familiar with the facts and possessed of an extraordinarily keen mind.

H. W. FOOTE.

Solubilities of Inorganic and Organic Compounds; by ATHERTON SEIDELL. Pp. vi, 569. New York, 1928 (D. Van Nostrand, \$8.00).—Every chemist is familiar with Dr. Seidell's well-known reference book on Solubilities. The present volume is a supplement to the second edition, and contains data published from 1917 to 1926. The material appears to be very complete, and its arrangement and the system of references to literature are convenient. The book will be a valuable addition to the original volume, which was getting out of date. H. W. FOOTE.

Colloid Symposium Monograph; edited by HARRY B. WEISER. Pp. 304. New York, 1928 (Chemical Catalogue Company, \$6.50).—This volume consists of twenty-four papers which were presented at the Fifth National Symposium on Colloid Chemistry in June, 1927, at the University of Michigan. Perhaps the article of most general interest was presented by Dr. Kruyt, who was the guest of honor, on "Unity in the Theory of Colloids." All the articles, however, are original contributions to Colloid Chemistry and of interest and importance in that field. H. W. FOOTE.

Chemical Encyclopaedia; by C. T. KINGZETT. 4th Edition. Pp. viii, 807. New York, 1928 (D. Van Nostrand Company \$10.00).—A book of this character, written by one man, is of necessity very largely a compilation from other reference works. It furnishes a large amount of information about many compounds and chemical products in regard to their composition, uses, properties, and methods of preparation. The book will probably be of service to schools and to the general reader. For the chemist, it is somewhat inadequate. H. W. FOOTE.

Enzyklopädie der technischen Chemie; edited by PROFESSOR FRITZ ULLMAN. 2d edition, Vol. I. Pp. viii, 808. Berlin, 1928 (Urban and Schwarzenberg, 48 Rm., bound). The first volume of the second edition of this very important reference work has just been issued. The editor expects that the entire work, in ten volumes, will be completed in five years. The volumes of the first edition were reviewed in this Journal frequently between 1922 and 1925. In this second edition, the very recent developments (as well as the older) are treated with a completeness which is only possible by having the various subjects written by specialists. Take, for instance, the preparation of absolute alcohol. The modern method, by distilling with benzol, is fully discussed, together with various suggested improvements up to the early part of 1927. Similarly, the synthetic production of ammonia is treated with a wealth of detail, including patents through 1926, theory, catalysts, and factory methods.

Over one hundred and fifty men, including many distinguished names, are contributors to this work. It may well take the place in Applied Chemistry which has been occupied by Abegg's reference work in the field of Inorganic Chemistry. H. W. FOOTE.

Creatine and Creatinine; by ANDREW HUNTER. Pp. 281. London and New York, 1928. (Longmans, Green and Co., Ltd., price, \$5.00.)—In view of the physiological importance of creatine and creatinine, Professor Hunter has rendered a distinct service to Biochemistry by his compilation (through 1926) of the extensive literature dealing with these compounds.

The first four chapters are devoted to a complete account of the chemistry and distribution in nature of creatine and creatinine, and the remaining five chapters to a discussion of the present status of knowledge and opinion concerning their physiology. The entire work is characterized by a pleasing brevity and clarity, and by a philosophical viewpoint, which is not only interesting, but also stimulating to chemical and physiological chemical research. The careful weighing of the merits and the inadequacy of each of the various theories, interpretative of the metabolic behavior of creatine and creatinine, is of the greatest value.

A. J. HILL.

Physical and Chemical Constants; by G. W. C. KAYE and T. H. LABY. Sixth Edition. Pp. 763. London and New York, 1928 (Longmans, Green and Co., \$4.75).—As the change in the new edition of this valuable work is slight, merely the addition of a page on the Thermal Conductivities of Gases, the reader is referred to the notice of the Fifth Edition which appeared in this Journal 14, 72, 1927.

The frequent reprintings indicate a wide and increasing appreciation of its worth.

F. E. B.

Intermediate Electricity and Magnetism; by R. A. HOUSTON. Pp. x, 170; 155 diagrams. London and New York, 1928 (Longmans, Green and Co., \$1.75).—This book is designed to serve students preparing for examinations of about the grade of university matriculation. There is nothing especially noteworthy in its contents; in fact it parallels very closely the sections on electricity and magnetism which may be found in any one of a dozen familiar text books of physics.

F. E. B.

Meteorology; by DAVID BRUNT. Pp. 112; 19 figs. London and New York, 1928 (Oxford University Press, \$1.00).—The publishers have allotted the preparation of the 47th volume of their *World's Manuals* series to the Superintendent of the Meteorological Services in the Air Ministry. It is something more than a primer and less than a treatise and aims to give the reader, in simple style and moderate compass, a sketch of the physical principles which are operative in producing those phenomena of the air which we call weather. From a consideration of the constitution of the atmosphere and its general circulation, with the effect of solar radiation on the variation of temperature; the author is able to explain the principal features of cyclonic depressions and other traveling disturbances in the atmosphere. Frequent illustration

and use is made of weather maps and meteorological observations but the subject of weather forecasting lies outside the scope of the book. The work is frankly intended only as an introductory volume but in it the general reader will find all the principal landmarks of this branch of science. F. E. B.

Essais de Classification Hélicoidale des Eléments Chimiques; by CHARLES JANET. Pp. 104; 4 folded plates. Beauvais, 1928 (Imprimerie Départementale de l'Oise).—Since the discovery of Moseley and the explanation of the periodic properties of the elements in terms of electron groupings, such elaboration of empirical diagrams as the author has here undertaken seems to promise little of constructive value. The student of chemistry may, however, find something of interest in the writer's description and accounting for the resemblances and differences of the elements as here set forth. F. E. B.

Grundzüge der Theoretischen Logik; by D. HILBERT and W. ACKERMANN. Pp. viii, 120. Berlin, 1928 (Verlag von Julius Springer).—This work on the algebra or calculus of logic exhibits the substance of various lectures on the principles and foundations of mathematics given by Professor Hilbert at the University of Göttinger, but owes its present form to the study and amplification of one of his pupils, Herr Ackermann.

Much as the progress of mathematics since antiquity is in greatest measure due to the development of a flexible and useful notation, so the introduction of a suitable symbolization has been found to be of indispensable assistance in the recent advance of the science of logic.

The present volume forms the 37th of the series entitled *Die Grundlehren der Mathematischen Wissenschaften*. In it the interested reader will find a full exposition of the methods of this calculus with extensive illustrative material. F. E. B.

Elements of Physics; by A. WILMER DUFF and HENRY T. WEED. Pp. ix, 555; 462 figs. New York, 1928 (Longmans, Green and Co.).—This book is of the class intended to interest the pupils of secondary schools in scientific principles and their application in familiar devices of everyday life. It will undoubtedly appeal to school teachers of science, although there is considerable hokum in some of the pictures. The name of the leading author is assurance, however, that the explanations are trustworthy and valuable as far as they go.

It is no legitimate criticism of the book, nor is it to be construed as in any sense a disparagement, but many college teachers cannot avoid the impression that such books are in some way responsible for the notable lack of interest of their students in physics after they come to college. Having had such a skimming course the student inclines to think he knows all about it and missing any especial novelty is much averse to searching more deeply into the science. F. E. B.

GEOLOGY.

Permian Ammonoids of Timor; by J. PERRIN SMITH. Jaarb. Mijnwezen in Ned.-Indie, Verh., 1926, I, 58 pp., 16 pls., 1927. *Ammonoidea Lëiostraca aus der Oberen Trias von Timor*; by GUSTAV VON ARTHABER. Ibid., II, 174 pp., 19 text figs., atlas of 20 pls., 1927.—The island of Timor in the East Indies has about 600 different kinds of Permian marine invertebrates, and Haniel in 1915 monographed 37 forms of ammonites from the first collection made by the Wanner expedition. Now Smith reports on the second collection made by the Jonker expedition. He finds 49 named species (17 new) in 23 genera. The Permian of Timor is said to be very thick, composed of limestones, marls, and tuffs, interbedded with diabase and melaphyre sheets, and is concordantly overlain, as in India, by marine Lower Triassic, though in Timor the very highest Permian is absent. Four distinct ammonite zones have been determined, but unfortunately in no place have any of them been found superposed. These zones are known by local names, with the Somohole as the lowest (9 species, of which 5 go up), followed by the Bitauini (29, 2 go up), Basleo (16, 6 go up), and Amarassi (8). Diener in Part 14 of "Fossilium Catalogus" (1921) lists 193 species in the Permian of the world, and with the 17 new ones described from Timor by Smith the total is now 210 forms in 41 genera (11 come from the Upper Carboniferous, and 10 go into the Triassic). It is interesting to note here that 35 forms in 13 genera occur in the Lower Permian of European Russia, 66 in 19 genera in the Middle Permian of Sicily, 39 in 19 genera in the Lower and Middle Permian of West Texas, 7 in 7 genera in the Upper Permian of the Salt Range, and 6 others in 3 additional genera in the Himalaya of India, with 49 in 23 genera in the four zones of Timor. These widely scattered regions have but a single species in common, and that is *Marathonites diblasi* of Sicily and the Salt Range, although five species of the former locality also occur in Croatia. The genera, however, are of very wide distribution, and many are world-wide in occurrence. Ammonite faunas are also often rich in specimens, single forms in Timor being represented in the Haniel collection by anywhere from 8 to 900 individuals, and yet 60 per cent of the forms are known by fewer than 8 specimens each.

"The Permian ammonoid fauna of Timor," according to Smith, "is the richest in the world, in genera, species and number of individuals collected. Its only rivals are Sosio in Sicily, and Texas, but it surpasses both. . . It is a curious mixture of primitive ancestral types with highly modified descendants. . . Here we have the past, the present and the future together, anachronistic genera from the Carboniferous, vigorous specializing genera characteristic of Permian, and some prophetic Triassic races. . . The

forebears of all the stately and beautiful genera of the Triassic may be seen in the simple and unpretentious forms of the Permian. . . Ontogeny in them repeats phylogeny with ideal simplicity and certainty" (pp. 1-2).

"We are apt to think of all genera as strictly monophyletic, but this is probably rarely the case. When two groups are very different, we give them different names; when they are moderately similar we call them by the same name. The life-history of any large stock is a stream and not a narrow line, and almost any fossil genus is really a cross-section of similar and parallel lines" (21). Different species of *Gastrioceras* have given rise to *Paralegoceras*, but "this does not make the genus polyphyletic, in fact, it is the probable mode of origin of most large genera, although this may sound unorthodox" (31). Smith also shows that Haniel had combined into one species five different forms. "These forms are differentiated almost down to the early adolescent stages, and do not intergrade after that time" (35).

The Upper Triassic of Timor, although thought to be not thicker than 7 feet, yielded the Jonker expedition nearly 10,000 specimens of ammonites, a collection said to be richer than even the celebrated one of Hallstatt in Austria. Locally, the limestone is one mass of Cephalopoda. These ammonites Von Arthaber and Diener (in an earlier monograph of 1923 he describes 226 forms of Trachyostraca) have divided into 328 distinctly named forms arranged in about 52 genera. Arthaber in the work above cited describes 102 forms (49 new) in 21 genera. Of these species, about 40 per cent are represented by from 1 to 5 specimens, about the same percentage have from 6 to 15 examples, and the rest have anywhere from 50 to 630. Of Trachyostraca there are about 2,700 specimens and of Leiostraca more than 7,200. The localities from which the material was collected are many, but all are isolated by Cenozoic deposits; the yield of each limestone outcrop ("block") was kept intact in the hope that faunal zones could be distinguished. In this hope Diener (1923) was fairly successful on faunal grounds, distinguishing Karnian and Norian time in many of the blocks, but Arthaber could not make out such with certainty, since the guide forms of both zones are mixed. In the field, no zones or beds can be distinguished. Therefore these one or two meters of limestone of the Upper Triassic period must represent a long geologic time (Karnian and Norian), with exceedingly slow deposition, possibly in water 500 fathoms or more deep, with the dead shells raining to the bottom.

Arthaber finds that about 50 per cent of the Leiostraca are restricted to Timor, and that out of the 102 named forms 57 are common to the Mediterranean and the East Indies. On the other hand, California has not a single one of the Timor species, only two closely related forms.

c. s.

The Cretaceous and Tertiary of Southern Texas and Northern Mexico; by EMIL BÖSE and O. A. CAVINS. *Cretaceous Ammonites from Texas and Northern Mexico*; by EMIL BÖSE. Univ. of Texas Bull. No. 2748, 357 pp., 19 pls., 1927.—The late Doctor Böse, along with the junior author of this bulletin, had since 1922 been employed as field geologist by the Richmond Petroleum Company of Mexico, and the chief geologic results of their last five years of work, here published, are of much importance to stratigraphers and petroleum geologists. On September 9, 1927, Böse was seriously injured at Sabinal, Texas, and died there on November 8; the work under review had, however, been completed and was seen through the press by the junior author.

In this report by Böse and Cavins, the whole Cretaceous of northeastern Mexico, about 9,000 feet thick, is described and correlated with that of southern Texas and that of Europe in far more detail than ever before. This is now possible due to the recent work done by Spath on the ammonites of the Albian and Cenomanian of Europe and Africa. To make his correlations clear, it was necessary for Böse to describe one new species of *Inoceramus* and 36 of ammonites (22 are new, with three new genera, *Adkinsia*, *Budaiceras*, and *Coahuilites*).

Böse, as heretofore, divides the Cretaceous into three main divisions: the Infra-Cretaceous (Neocomian of southern and central Mexico, not present in Texas); the Meso-Cretaceous (all of the Comanchian and the lower Eagle Ford, the equivalents of the Aptian, Albian, and Cenomanian of Europe); and Supra-Cretaceous (upper Eagle Ford, Austin, Taylor, Navarro, and Escondido of Texas, equivalent to the Turonian, Coniacian, Santonian, Campanian, and Maestrichtian of Europe). The whole is divided into twenty-seven zones, on the basis mainly of the ammonites and echinoids, with some help from the bivalves such as the caprinids, rudistids, Inocerami, and Trigonias.

The local paleogeography is described in some detail and further cartographic information is to be found on Plate 19. This study leads on to the time of mountain-making that began in northern-eastern Mexico in Campanian time, as seen in the movements and final vanishing of the seas, and ended with the Laramide orogeny that did not cease much before the close of the Eocene. When viewed in the light of the stratigraphy of Mexico as a whole, it is seen that the medial axis separating the Gulf of Mexico extensions from those of the Pacific began to rise as early as Cenomanian time, while the actual folding other than that due to igneous intrusions took place in the early Cenozoic (p. 142).

C. S.

The Coral Reef Problem; by WILLIAM MORRIS DAVIS. Amer. Geog. Soc., Special Pub. No. 9, 596 pp., 227 text figs. (mainly

block diagrams by the author), 1928.—This very detailed and thoroughly argued book, and that other labor of love, the biographical memoir of Grove Karl Gilbert in the National Academy series, are the crowning works of Professor Davis's long and very active life. In them, his beloved science of Physiography is given a wider application than ever before, and the volume on the coral reef problem will surely be regarded as a great classic, worthy of close association with Darwin's "Structure and Distribution of Coral Reefs" (1842) and Dana's "Corals and Coral Islands" (1872). Due to Louis Agassiz and his great son Alexander, the Museum of Comparative Zoology at Harvard has long been a sort of storm center for the coral reef problem, from which have radiated at different times the various views of Alexander Agassiz, of Daly, and of Davis.

The author tells us that he became acquainted with the theory of coral reef growth as expounded by Darwin, while a student of Professor Shaler at Harvard sixty years ago. It was not until thirty years later, however, "while drawing an ideal block diagram of a barrier reef for an elementary text-book," that the idea came upon him full force that "if such reefs are formed by upgrowth around subsiding islands, as Darwin's theory proposed, the islands should have embayed shore-lines." This Darwin did not know. "Then, on discovering from the charts of such islands that they do have embayed shore-lines, the theory of subsidence seemed to me to be a true theory." Later this conclusion was much shaken by the work of Alexander Agassiz and the counter arguments of Semper, Murray, and Guppy, none of whom, however, gave any thought to embayed shore-lines. Still later, on looking up Dana's report on the geology of the Wilkes Expedition (1849), Davis learned to his surprise that Dana "had clearly made application of the principle of shore-line embayments to the coral reef problem a long half-century before and had thus provided for Darwin's theory a support greatly needed by it" (pp. 546-7).

Davis spent the greater part of 1914 on the Pacific, visiting "thirty-five reef-encircled islands as well as a long stretch of the Queensland coast back of the Great Barrier Reef of Australia—a glorious observational opportunity." Later, in 1923, he also visited the Lesser Antilles, "where the peculiar features expectable on marginal-belt islands were found to be developed in the most striking manner. For there the reefs [were] mere timid Postglacial novices . . . strongly unlike the stalwart veterans of the true coral seas in the Pacific." Davis has also studied what is printed on the coral reef problem, citing in his bibliography works to the number of 783, from 425 different authors. No one has worked more faithfully to understand the growth of reef corals on, and the physiography of, subsiding oceanic islands.

Darwin's theory had "world-wide adoption" between 1840 and

1870, but from then on to 1910 met with more frequent objection. However, the only serious objection, Davis says, "concerns the islands of the marginal belts of the coral seas, for the explanation of which Darwin's theory must be supplemented by the wholly new process of low-level abrasion, first brought into the problem in recent years by Daly" (p. 548).

What Darwin did not see, but Dana did, is here developed into its full significance, namely, "the occurrence of embayed shore-lines back of upgrowing barrier reefs as a necessary consequence of Darwin's theory." Such are of universal occurrence on the oceanic islands back of the reefs. Moreover, Darwin and Dana's theory of widespread ocean-bottom subsidence must now give way to "Molengraaff's concept of the relatively local and isostatic subsidence of volcanic islands—a concept that is entirely compatible with Darwin's theory of coral reefs." But subsidence can not have been faster than the rate of reef upgrowth. In fact, "subsidence has been much slower than the ordinary rate of island displacement . . . and also much slower than the inferred rate of changes of ocean level during the Glacial period" (p. 544). "The rising and sinking areas of the Pacific must be subdivided in a much more complicated fashion than Darwin supposed; and even in their reduced dimensions the main movements will probably be found to be complicated by many minor movements" (p. 39).

"The main conclusion of my many pages is that Darwin's theory of upgrowing reefs on intermittently subsiding foundations, extended by introducing the effects of Glacial changes of sea level and temperature, as proposed by Daly, and by adding such minor modifications as may be called for in special cases, will deservedly regain in the present century the general acceptance which it enjoyed through the middle of the past century."

Both Professor Davis and the American Geographical Society are to be congratulated upon the production of this splendid book upon a much debated subject. c. s.

Earthquakes in Southern California.—A few years ago Dr. Bailey Willis, formerly of the U. S. Geological Survey, now professor emeritus at Stanford University, made the prediction that a severe earthquake was likely to occur in Southern California in from 3 to 10 years. This suggestion was naturally disquieting to the city of Los Angeles and led to an increase in insurance rates, by which building operations were reduced.

The opposite view is now (1928) presented by Dr. H. T. HILL, also formerly of the U. S. Geological Survey, in a book on "Southern California Geology and Los Angeles Earthquakes." Hill's argument is chiefly based upon the probable effects of the great weight of the Pleistocene ice sheets in causing (in accordance with isostasy) a sinking of the earth's crust beneath the ice and uprisings elsewhere, with the result of promoting many dis-

placements at that time in Southern California; but it is maintained by Hill that since the disappearance of the ice sheets, Southern California has been passing through a period of decline in seismic activity. This view is not likely to carry conviction among geologists or seismologists. In the present insufficient knowledge of Southern California earthquakes, a policy of safe building construction would seem to be wise. W. M. D.

United States Geological Survey; GEORGE OTIS SMITH, Director. Recent publications of the U. S. Geological Survey are noted in the following list. (See earlier July, 1928, p. 84.)

TOPOGRAPHIC ATLAS.—Thirty-two sheets.

PROFESSIONAL PAPERS.—No. 142, E, The molluscan fauna of the Alum Bluff Group of Florida; by JULIA GARDNER. Part V. Tellinacea, Solenacea, Mactracea, Myacea, Molluscoidea. Pp. i-iv, 185-249, i-iii (index); pls. xxix-xxxvi. This is the fifth of the series of papers on the Alum Bluff mollusks and the final paper on the pelecypods; it includes descriptions of many new species.

No. 153. Studies of Basin Range structure; by G. K. GILBERT. Pp. vii, 92; 40 pls. (including 3 maps), 57 figs. This gives the results of a broad plan to reexamine critically the subject of Basin Range structure, one of the last projects of the late author. It contains chapters on the Wasatch, Fish Springs, and House Ranges, in Utah, the Klamath Lake region, Oregon, and the fault scarp near Bakersfield, California. The chapter on the Wasatch Range was completed and that on the Fish Springs and House Ranges nearly completed by Mr. Gilbert before his death. The other chapters are published substantially as he left them. The paper sets forth Mr. Gilbert's mature judgment on the validity of a concept which he first announced in 1874.

BULLETINS.—No. 775. Geology and lignite resources of the Marmath Field, Southwestern North Dakota; by C. J. HARES. Pp. vi, 110; 14 pls. (including 2 maps) in pocket, 1 fig. The extent and importance of the deposits of lignite in North Dakota is difficult to grasp. It is estimated that in the field investigated in the southwest corner of the State the reserves amount to 15,756,060,000 tons. The reserve supply of fuel in North Dakota will sooner or later be called upon to supply light, heat, and power to the inhabitants of this and surrounding regions.

No. 793. Economic geology of the Castlegate, Wellington, and Sunnyside quadrangles, Carbon County, Utah; by F. R. CLARK. Pp. vi, 165; 22 pls. (including 1 map), 3 figs. This gives the results of an investigation of the amount of coal underlying a considerable area in Carbon County, Utah. From one to twelve workable beds occur in different parts of the region, one or two beds having a maximum thickness of 19 feet. The total amount of recoverable coal remaining is estimated at 2,286 million tons.

No. 788. Topographic instructions of the United States Geo-

logical Survey; by C. H. BIRDSEYE, chief topographic engineer. Pp. v, 432; 29 pls. (including 2 maps), 18 figs.

No. 802. Bibliography of North American geology for 1925 and 1926, by J. M. NICKLES. Pp. iii, 286. This series of bibliographies covers the period from 1732 to 1926; the volume cites nearly 3,000 publications issued during the two years named in the title.

WATER SUPPLY PAPERS.—Nos. 540, 571, 573, 576, 581, 582, 585, 587.

U. S. Bureau of Mines; SCOTT TURNER, Director. The recent publications of the Bureau of Mines include the following (see earlier, July 1928, p. 83).

MINERAL RESOURCES of the United States, 1925, in two bound volumes; FRANK J. KATZ, Chief Engineer, Division of Mineral Statistics. (Price \$1.00 per volume.)

Part I. Metals. Pp. xi, A 123, 768; 4 figs. Figure 1 gives the world's production of antimony for 1912-1925 in metric tons, also the New York prices. Figures 2 to 4 are devoted to tin; Fig. 2 gives the amount imported and recovered in the U. S.; Fig. 3 the uses of tin; Fig. 4, the world's production-by countries in 1925.

Part II. Nonmetals. Pp. vi, 615. Preliminary Resources of the United States in 1927. Pp. A. 120. Introduction by FRANK J. KATZ; Statistics assembled by MARTHA B. CLARK. (Published August 13, 1928; price 20 cents.)

BULLETINS. No. 284. Production and development problems in the Powell Oil Field, Navarro Co., Texas; by H. B. HILL and CHASE E. SUTTON. Pp. v, 123; 35 figs. (45 cents.)

No. 291. Tabulated analyses of representative crude petroleum of the United States; by N. A. C. SMITH and E. C. LANE. Pp. 69. (15 cents.)

Technical Papers. Nos. 17, 409, 422, 424, 427, 429, 430, 433.

Colorado Bureau of Mines; JOHN T. JOYCE, Commissioner. Annual Report for the year 1927. Pp. 70. Denver, 1928.—Prior to the World War, Colorado ranked first in the production of gold and silver in the country and held a leading position in other industrial metals. The abandonment of the Denver, Salida and Pueblo smelters in 1919 and 1921 had an unfortunate effect, only two smelters, at Durango and Leadville, being still in operation. The wealth of the State in mineral resources, however, assures a full return to prosperity when modern facilities in reduction, milling and smelting are supplied.

Virginia Geological Survey.—Dr. Wilbur A. Nelson, State Geologist of Virginia from 1925 to 1928, has resigned his position to devote himself to his duties at the University of Virginia. In his place Mr. Linwood H. Warwick, Chief Clerk of the Survey, has been appointed Acting Head of the Virginia Geological Sur-

vey. The offices of the Survey will be at the University of Virginia as heretofore.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Handbuch der Biologischen Arbeitsmethoden, herausgegeben von DR. EMIL ABDERHALDEN; Berlin 1927 (Urban and Schwarzenberg, Berlin, N. 24, Friedrichstrasse 105 B).—Three parts of this valuable publication are noted here. Teil 1, 2 Hälfte, Heft 4, pp. 660-702, contains two articles by W. A. COLLIER. In the first paper, "Methods for studying parasitic worms," 32 pp., the author presents methods used by various investigators for collecting trematodes, cestodes and nematodes and their eggs from the intestine, bladder, respiratory and circulatory systems, and organs of man and other animals, and for preserving the adult worms, the larvae, and the eggs of these worms. "Rearing parasitic worms," 10 pp., the second paper, reviews the methods which during recent years have been developed for rearing microfilaria, cysticerci, miracidia, Ascaris, Ankylostoma and Uncinaria, Strongyloides, Nematosis, Angiostomum and Rhabditis. A list of references to original papers is furnished.

Teil 2, 2 Hälfte, is devoted to methods used in studying the biology of fresh water. Heft 1 consists of a long article, "*Die Arbeitsmethoden der Fischereibiologie*," by HANS HELMUT WUNDSCH, pp. 853-1208; 108 figs., 4 pls. This is a remarkably comprehensive exposition of methods employed not only in the study of fresh-water fishes but of all organisms encountered under both natural and artificial conditions in work relating to hydrobiology and fisheries, using the latter term in its broadest sense. Section I describes equipment and instruments used in mobile laboratories and on all sorts of expeditions for taking water samples, depth measurements, collection of plankton, shore and bottom investigations, transportation, sifting and study of samples, and microscopes for researches upon the microorganisms contained in them. Section II takes up procedure followed in studies of lakes, ponds, rivers and brooks, with suggestions as to the evaluation of results. Section III discusses methods for the chemical study of water as related to "Fischereibiologie," consideration being given to measurement of free oxygen, oxygen evaporation, calcium-permanganate consumption, hardness, the rôle of H-ion concentration, and the instruments used in such studies. In section IV are discussed methods for the determination of age in fishes, and, in section V, for weighing and measuring fishes. Sections VI and VII are given up to a comprehensive explanation of methods for studying the foods and diseases of fishes. Section VIII emphasizes methods concerned in pond measurement, while IX is devoted to methods of studying pollution

in ponds; X takes up methods used in physiological researches, particularly those focussed upon the gaseous content of water, gastric juice and hepatopancreatic extract in fishes; XI explains methods of drainage; XII considers use of poisons, explosives, electricity and spears in fish capture; XIII, methods of marking fishes; XIV describes methods for procuring fishes for investigations.

Heft 2 contains 6 articles as follows: *The methods in zoogeography of fresh water*, by SVEN EKMAN, pp. 1211-1248; *Floating stations*, by H. C. REDEKE, pp. 1249-1257, 1 fig.; *The employment of interferometers in fresh-water investigations*, by REINHARD DEMOLL, ADOLF SEISER and LUDWIG WALZ, pp. 1259-1278; *The artificial arrangement of vacant land reservoirs and marsh trenches for biological and experimental studies and for instruction*, by CARL J. CORI, pp. 1279-1286, 1 fig.; *Limnological laboratories*, by FR. LENZ, pp. 1287-1368, 30 figs; and *The light-relationship of fresh water*, a fundamental exposition of one of its chief problems on a methodologic basis, by EINAR NAUMANN, pp. 1369-1384, 5 figs. Together these papers contain a wealth of information. The first is supplemented by a bibliography of nearly 200 titles.

S. C. B.

A Pocket Medical Dictionary. Ninth Edition Revised, 9 x 16 cm., by GEORGE M. GOULD. Philadelphia, 1928 (P. Blakiston's Son & Co.)—This is the ninth revised edition of a deservedly popular "pocket" dictionary of the medical sciences. The reviewer has tested its up-to-date character by searching for a number of comparatively recent additions to the medical vocabulary, such as glutathione, glukhorment, autacoid, chronaxie, tularemia, zygote and bios; all of which had been included. The form and make-up are very effective for the purposes involved.

L. B. M.

Recent Advances in Physiology. Third Edition. Pp. x, 403; by C. LOVATT EVANS. Pp. xiii, 403. Philadelphia, 1928 (P. Blakiston's Son & Co., \$3.50).—Realizing that physiology as a science has at length accumulated a large number of facts, the author has accordingly brought together some of the newer attempts to interrelate or explain them. He has thus produced one of the few volumes that deal primarily with the theoretical aspects of the science. It would probably be more logical to designate the contribution as "Theoretical Physiology" in analogy with the Theoretical Physics and Theoretical Chemistry manuals of the present day. Only the seriously minded student will find such a book inspiring, for it quite properly assumes a preliminary acquaintance with something more than the elements of the science. The volume is critical in character and ought to be stimulating to advanced workers who seek a discriminating guide to the enormous literature of the subject. The discussions of chronaxie, conditioned reflexes, the nature of the nervous impulse, cell oxidations, ionic interchanges in the

blood, the chemistry and energetics of muscular contraction may be cited as illustrations of the types of themes that are dealt with; and three revisions in three years attest the up-to-date character of this new edition by a keen English physiologist. L. B. M.

Bureau of Standards Journal of Research.—With July 1928, the Bureau of Standards, Dr. George K. Burgess director, has begun a new monthly periodical. This will contain the research papers of the Bureau and also critical reviews of papers in science and technology. By this means pure and applied science will be brought together in one periodical; there will also be less delay between discovery and application. It is obvious that all engaged in scientific or technical work will find this journal essential.

The two series of research papers, thus far issued as "Scientific Papers" and "Technologic Papers", will now be united in one publication which will have the more commonly accepted and convenient octavo form, $5\frac{7}{8} \times 9\frac{1}{8}$ inches. Each semiannual volume will have its own index; also a cumulative consolidated index will be included in the Bureau's list of publications as heretofore. It may be added that the Bureau has published forty-four volumes of the Scientific Papers and Technologic Papers, twenty-two of each. These have included 942 research papers, 572 on fundamental science and 370 on applied science.

This important addition to monthly scientific literature may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., on the payment of \$2.75 for this country (also Canada, Mexico, Cuba); or \$3.50 for other countries). The semiannual volume bound in blue buckram will be furnished at a price quoted on request.

PUBLICATIONS RECENTLY RECEIVED.

The Engineer, His Word and His Education; by Robert L. Sackett. Boston, 1928 (Ginn & Co., \$1.40).

Assimilation and Petrogenesis, Separation of Ores from Magmas; by John Stansfield. Urbana, Illinois, 1928 (Valley Publishing Co., \$3.50).

The Technology of Low Temperature Carbonization; by Frank M. Gentry. Baltimore, 1928 (Williams & Wilkins Co., \$7.50).

Rhodesian Man and Associated Remains; by W. P. Pycraft, G. Elliot Smith, et als. London, 1928 (British Museum of Natural History).

A Pocket Medical Dictionary; by George M. Gould. Ninth Edition, Revised. Philadelphia, 1928 (P. Blakiston's Son & Co.).

Recent Advances in Physiology; by C. Lovatt Evans. 3d Edition (P. Blakiston's Son & Co., \$3.50).

Catalogue of the Pontian Bovidae of Europe in the Department of Geology, British Museum; by Guy E. Pilgrim and Arthur T. Hopwood. Quarto. British Museum, London, 1928.

The Ferns; Volume III; by F. O. Bower (The Macmillan Company).

Engines; by E. N. da C. Andrade. New York, 1928 (Harcourt, Brace & Co., \$3.00).

Toxicology or The Effects of Poisons; by Frank P. Underhill. Second Edition, revised, enlarged. Philadelphia, 1928 (P. Blakiston's \$2.50).

The Two Solar Families; by Thomas C. Chamberlin. Chicago, 1928 (Univ. of Chicago Press, \$2.50).

Laboratory Manual, arranged to accompany the third edition of "A Course in General Chemistry"; by Wm. McPherson, Wm. E. Henderson and Wm. L. Evans. Boston, 1928 (Ginn & Company, \$1.20).

Traité de Chimie Colloïdale, edited by Robert H. Bogue, translated by Jean Barbaudy Tome I. Chimie Colloïdale Théorique. Paris, 1928 (Librairie Scientifique Hermann, 80 francs).

La costituzione e l'evoluzione della materia; by Mario Motta. Milan, 1928 (Loescher & Co.).

OBITUARY.

LORD RICHARD BURDON HALDANE died on August 19 at the age of seventy-two years. He was eminent in philosophy, and as Gifford lecturer in St. Andrews he discussed the subject of "The Pathway to Reality," published in two volumes in 1903-1904. Another notable work, issued in 1921, was entitled "The Reign of Relativity." He will, however, be longest remembered for his services at the War Office from 1906 to 1912, and as a member of the Judicial Committee of the Privy Council after the close of the war in 1918.

SIR HORACE DARWIN, the youngest son of Charles Darwin, died on September 23 at the age of seventy-seven years. He was an able civil engineer and was best known for his work in the invention and perfection of scientific instruments.

DR. JOHN RENNIE, lecturer in agricultural zoology in the College of Agriculture of the University of Aberdeen, died on August 30 at the age of sixty-three years.

DR. E. C. GREY, formerly professor of chemistry at the University of Cairo, died on August 10.

DR. WILHELM WIEN, professor of experimental physics in the University of Munich, died recently at the age of sixty-four years.

DR. ANDREW HENRY PATTERSON, professor of physics in the University of North Carolina from 1908 and dean of the School of Applied Science from 1911, died recently at the age of fifty-eight years.

DR. BENJAMIN WARNER SNOW, professor of physics at the University of Wisconsin, 1893-1926 when he retired, died on September 21 at the age of sixty-eight years.

DR. EGERTON CHARLES GREY, worker in biochemistry, died on August 10 at the age of forty-one years.

DR. ROBERT KNOX, president of the Röntgen Society, died on September 21 at the age of sixty years.

DR. HARRIS MILLER BENEDICT, professor of botany at the University of Cincinnati, died on October 17, as the result of an automobile accident; he was fifty-eight years old.

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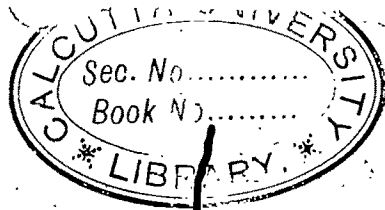
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DECEMBER 1928

KANSAS PERMIAN INSECTS. PART 12. THE FAMILY DELOPTERIDAE, WITH A DISCUSSION OF ITS ORDINAL POSITION.

R. J. TILLYARD.

[Studies aided by a grant from the Marshall Fund of the National Academy of Sciences.]

Having completed the study of the family Lemmatophoridae, it seems logical to continue with the study of the family Delopteridae, which Sellards placed next to it in his work (1909, p. 168). Sellards placed both these families in the order Protorthoptera; and it is quite evident, from his arrangement of the figures on p. 164 of his work, that he assumed the existence of a close relationship between the two genera *Delopterum* Sell. and *Lisca* Sell. Of the hindwings in *Delopterum* he remarks:—

"The hind wings are of approximately the same length as the front. They are probably expanded and plicated as in other families of this group."

As I had already found many errors in Sellards' work on the Lemmatophoridae, I approached the study of the Delopteridae with a determination to take nothing for granted, but to draw and study every available specimen and make my own conclusions as to their classification and affinities, without being previously influenced by Sellards' work. Although I have placed the family Lemmatophoridae in an order, Protoptera, distinct from the order Protorthoptera, yet that family does possess two characters which are essential to any group having Protorthopteroid affinities, viz. the presence of the convex anterior median, MA, and, in the hindwing, the development of an expanded anal area or fan. The first thing I discovered about the family Delopteridae, when I came to study it, was that its members possess *neither* of these characters, and, indeed, the specimens show quite clearly a Psocoid rather than a Protorthopterous facies. The correct understanding of the

group rests mainly on the careful working out of the differences between fore and hind wings. I think it will be best to give in detail the steps by which I arrived at the conclusions stated in this part.

In the Yale University Collection, I found twenty-nine specimens which can be classified at a glance as Delopteridae from Sellards' figures. Of these, only about twenty were well enough preserved to be drawn with accuracy. Having drawn these carefully, all at the same magnification ($\times 24$), I made a rough classification of the venational types, in order to see whether more than one genus was represented. The result was that the wings could be easily sorted into two main groups, as follows:—

(1) Distal end of the shortened Sc more or less clearly forked. Costal space relatively broad. M arising from Cu_1 well away from base of latter vein, somewhere about the level of origin of Rs. Main stem of Cu_1 very strong and convex. Basal part of wing comparatively broad.

(2) Distal end of the shortened Sc obsolescent, not clearly forked. Costal space relatively narrow. M arising from Cu (not Cu_1), very close to base, well before origin of Rs. *The strong, convex main stem of Cu_1 replaced by an equally strongly impressed concave vein, apparently by fusion of the original veins Cu_1 and Cu_2 together in the anal furrow, the only free portion of Cu_1 left being the distal fork Cu_{1a} , which is weakly convex.* Basal part of wing comparatively narrow.

Superficially, one might be tempted to allocate these two types of wing to two distinct genera within the family. But the character emphasized in (2) by the use of italics is such an extraordinary one, that it at once occurred to me that it might possibly be diagnostic of the hindwing, supposing that Sellards was in error in placing these insects in the Protorthoptera and assuming that their hindwings had an expanded anal area. I therefore searched through the twenty-nine specimens for signs of an undoubted hindwing, and found two in which the thorax and portions of the wings were preserved. One of these shows a hindwing partly exposed below a fore, and a second, after removal of some overlying rock, yielded an almost complete hindwing, in position, attached to the metathorax. A study of these two hindwings *in situ* showed that my supposition was correct.

The Delopteridae, then, are not Protorthopteroid in any sense, for they lack two essential characters of the order, viz.

the presence of MA and of an expanded anal area in the hindwing. Rather, they belong to the Psocoid complex both in their general venational scheme and in the shape and venation of the hindwing, though they stand out markedly from all known groups in the extraordinary formation of the cubitus in the hindwing.

Are the Delopteridae, then, sufficiently close to true Copeognatha or Psocoptera to allow of their being included in that order? I think we can best decide this by first studying the family in detail and then comparing its characters with those of the Copeognatha and other orders.

Family DELOPTERIDAE.

Small insects (forewing 3 to 7 mm. in length) with small globular head, elongate submoniliform antennae, short legs (tarsi not preserved); the abdomen shorter than the wings; cerci very short, with few segments. Fore and hind wings similar in outline, but the hind somewhat shorter than the fore, with narrower costal and anal areas. Sc short, never reaching beyond half-way, forked distally in forewing only. Rs three-branched. M a concave vein arising from Cu, two-branched. Cubitus very different in fore and hind wings; in forewing, Cu₁ is a strong, convex vein, simple or forked, Cu₂ a weak concave vein, simple; in hindwing, *the cubitus is a single strong but concave vein*, with distal fork apparently representing Cu₁ and short distal end of Cu₂. Two anal veins in both wings.

Three genera appear to be represented, as follows:—

1. Cu₁ in forewing either simple, or straight, with weaker descending veinlets, not forming a true fork. 2.
Cu₁ in forewing clearly forked, the fork enclosing, with the posterior margin, an areola postica of the Psocoid type.
Genus *Delopsocus*, n. gen.
(Genotype:—*Delopsocus elongatus* (Sell.).)
2. Forewings very narrow basally, less than 3 mm. long; Rs with a terminal fork only. Genus *Permembia*, n. gen.
(Genotype:—*Permembia delicatula*, n. sp.)
Forewings of normal width, 4 mm. or more long; Rs three-branched. Genus *Delopterum* Sell.
(Genotype:—*Delopterum minutum* Sell.)

Genus *Delopterum* Sellards.

(Figs. 1-3.)

Delopterum Sellards, 1909, p. 168, and p. 164, Fig. 16.

Forewings 4 to 5 mm. in length, of normal width. Sc forking a little distad from level of origin of Rs, well before half-

way. Rs three-branched, the main fork near middle of wing, and an extra and much smaller fork distally on R_{2+3} . Rs and M forking at very nearly same level; main stem of M very faint. Cu_1 reaching well beyond half-way along posterior margin, either simple or with two weak descending branches.

Genotype:—*Delopterum minutum* Sell.

Horizon:—Lower Permian of Kansas.

Only two rather closely allied species can be distinguished, as follows:—

Cu_1 with descending branches. R_2 turned sharply upwards, concave to R_1 *D. dubbari*, n. sp.
 Cu_1 simple. R_2 normal, slightly convex to R_1 *D. minutum* Sell.

Delopterum minutum Sell.

(Fig. 1.)

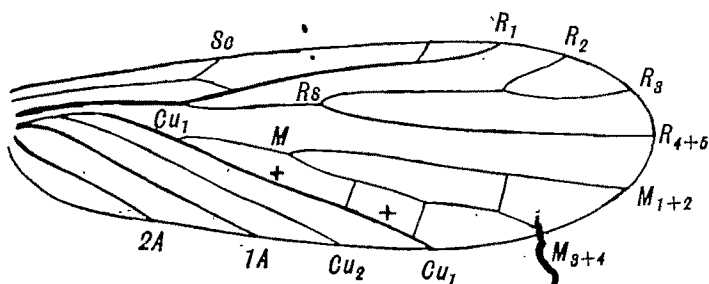


Fig. 1. *Delopterum minutum* Sell. Forewing. Length 4.5 mm. Specimen No. 5385. Note the convex Cu_1 , indicated by +.

Forewing:—Length 4.5 mm.; greatest breadth 1.4 mm.; ratio of length to breadth 3.2. Sc ending at about one-third in a definite fork. R_1 slightly bent at origin of Rs, and its distal course from there on slightly waved; a very faint veinlet borders the pterostigma basally. Fork of R_{2+3} at level of end of R_1 ; R_2 convex to end of R_1 ; R_{4+5} ending at the well-rounded apex of the wing. Branches of M diverging only slightly; a faint cross-vein is indicated between them distally, and two more between M_{3+4} and Cu_1 , the former vein being slightly bent in consequence. Cu_1 ending at about two-thirds along posterior margin; Cu_2 diverging but little from it, ending at about half-way. Anal veins not diverging distally.

Types:—*Holotype forewing*, No. 264 in Sellards' Collection. *Paratype forewing*, Specimen No. 5385a in Yale University Collection, and its counterpart No. 5385b in Cawthron

Institute Collection. Poor specimens belonging to the genus *Delopterus* and placed in this species with some doubt:—Nos. 5393a-b, 5394a in Yale University Collection, and No. 5394b in Cawthron Institute Collection.

Delopterus dunbari, n. sp.

(Figs. 2, 3.)

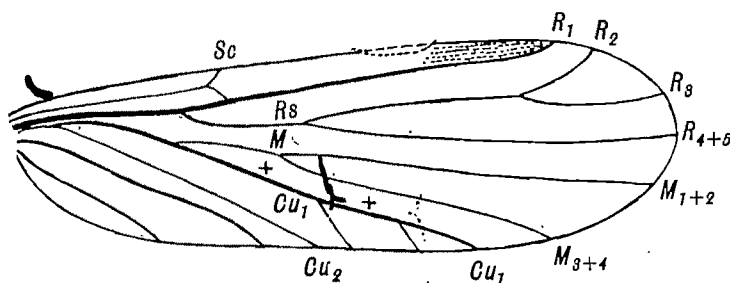


Fig. 2. *Delopterus dunbari*, n. sp. Forewing. Length 4.6 mm. Specimen No. 5392. Note the convex Cu_1 , indicated by +.

Forewing:—Length 4.6 mm.; greatest breadth 1.5 mm.; ratio of length to breadth 3.1. Differs from forewing of *D. minutum* Sell. in the slightly narrower costal space, with R_1 not bent at origin of Rs and much straighter distally; no

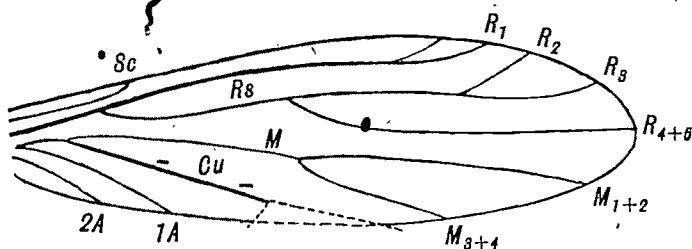


Fig. 3. *Delopterus dunbari*, n. sp. Hindwing. Length 4.3 mm. Specimen No. 5402. Note the concave main stem of Cu, indicated by —.

pterostigmatic cross-vein; pterostigma slightly pigmented; Rs more curved at origin; R_2 upturned and concave to R_1 ; branches of M diverging considerably; no cross-veins present; Cu_1 ending well beyond two-thirds, and having two descending branches; Cu_2 ending a little before half-way along posterior margin; anal veins diverging distally.

Hindwing.—Length 4.3 mm.; greatest breadth 1.2 mm.; ratio of length to breadth 3.6. It differs from the forewing in the much less broadly rounded apex, the very short, simple Sc, the more curved distal portion of R_1 , the more basal positions of the origins of Rs and M, and the reduction of the anal area, with consequent shortening of the anal veins. The special peculiarity of the hindwings of this family is well shown in the strongly *concave* main stem of Cu, which runs straight and without any branches to the point, very close to margin, where a break in the rock obliterates its distal end. The upturned R_2 is the diagnostic character by which this type of hindwing can be correlated with this species.

Types.—*Holotype forewing*, Specimen No. 5392a in Yale University Collection, with its counterpart No. 5392b in Cawthron Institute Collection; *paratype hindwing*, No. 5402 in Yale University Collection; (this specimen also shows a fragment of body, and portions of the two wings on the side opposite the almost complete hindwing shown in Fig. 3). Specimens assigned to this species with some doubt: Nos. 5387a-b, 5391a-b, 5397, 5399 all in Yale University Collection except the two counterparts, which are in Cawthron Institute Collection. No. 5400a-b, showing two wings folded together, and No. 5388a-b (hindwing) may be doubtfully placed here; both are in the Yale University Collection.

Genus *Delopsocus*, n. gen.

(Figs. 4-9.)

A genus containing species considerably larger than those in *Delopterum* Sell. and differing from them in the structure of Cu. In the forewing, Cu_1 ends in a conspicuous fork of the type found in *Psocidium*, i.e. with a more or less arched Cu_{1a} bounding, with the shorter Cu_{1b} and the posterior margin, a triangular *areola postica* (Fig. 4, ap). In the hindwing, the strong concave stem of Cu forks well before the margin into a convex Cu_1 analogous in position to Cu_{1a} of the forewing, and a concave Cu_2 analogous in position to Cu_{1b} in forewing.

Sellards' problematical species *Delopterum latum* must be included in this genus in the form of Cu_1 . The fourth branch of Rs ending indeterminately in the wing-membrane is surely an aberrancy. The formation of M shown in Sellards' figure (1909, p. 164, Fig. 17) indicates that this species was founded on a hindwing, and the very short, indeterminate Sc points in

the same direction. The broadly rounded anal area with slight inbending of the posterior margin at Cu_2 agrees with similar characters of several forewings in the Yale University Collection, which I therefore consider to be the missing forewings of this species. The genus will then contain three species, distinguished as follows:—

1. Forewing with Sc reaching to about half-way. ... *D. elongatus* Sell.
- Forewing with Sc ending up well before half-way. 2.
2. Forewing comparatively narrow, with a dark band crossing it in the region of the pterostigma and extending basad along the posterior margin right to the base; posterior margin without inbending at Cu_2 ; 2A simple. *D. fasciatus*, n. sp.
- Forewing broader, without any conspicuous color-pattern; posterior margin with a marked inbending at Cu_2 ; 2A forked. *D. latus* Sell.

Delopsocus elongatus (Sell.).

(Figs. 4, 5.)

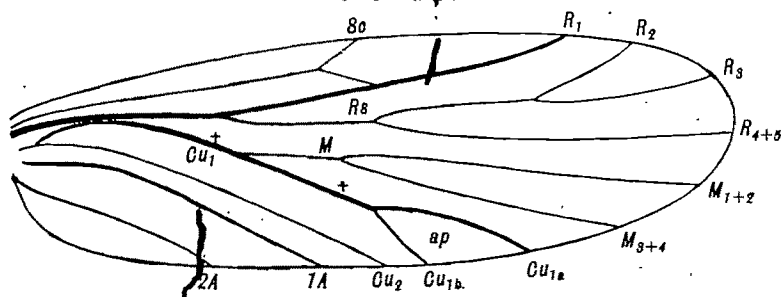


Fig. 4. *Delopsocus elongatus* (Sell.), n. gen. Forewing. Length 6 mm. Specimen No. 5386. Note the convex Cu_1 , indicated by +. ap, areola postica.

Delopterium elongatum Sellards, 1909, p. 168 and p. 164, Fig. 20.

Forewing:—Length 6 to 7 mm.; greatest breadth 1.9 to 2 mm.; ratio of length to breadth 3.4 to 3.5. Wing entirely without color-pattern. Sc ends up in a symmetrical fork of which the lower branch reaches R_1 just above the primary fork of R_s . (Sellards shows Sc as ending indeterminately at this point, but this is surely an error due to his not noticing the fork, which is very weakly impressed in some specimens.) 2A simple.

Hindwing:—Length 5.9 mm.; greatest breadth 1.9 mm.; ratio of length to breadth 3.2. This fine hindwing (Specimen No. 5389, Fig. 5) is associated with this species on the general shape and proportions of the wing, on the length of Sc, which

is much longer than in other hindwings, and on the comparatively narrow anal area. Costa narrow; Sc not forked, but ending indeterminately a little before level of fork of Rs;

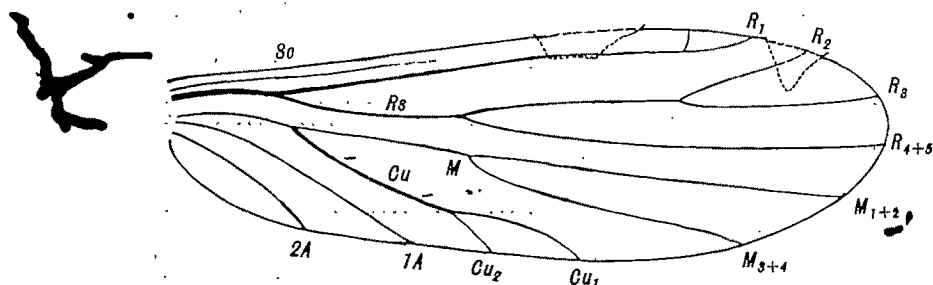


Fig. 5. *Delopsocus elongatus* (Sell.), n. gen. Hindwing. Length 5.9 mm. Specimen No. 5389. Note the concave main stem of Cu, indicated by —.

pterostigma slightly pigmented; Cu and anal veins all slightly diverging from one another.

Types.—*Holotype forewing* Specimen No. 61 in Sellards' Collection. *Paratypes*.—*Forewing*, Specimen No. 5386a

Delopsocus fasciatus, n. sp.

(Figs. 6, 7.)

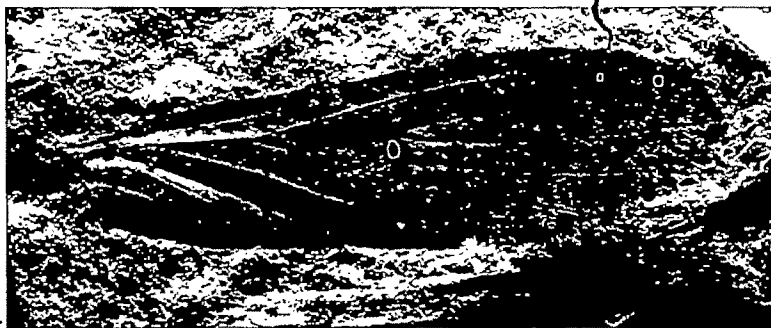


Fig. 6. *Delopsocus fasciatus*, n. gen. et sp. Forewing. Length 6.7 mm. Specimen No. 5377. Photograph by W. C. Davies.

(Fig. 4) in Yale University Collection, with counterpart No. 5386b in Cawthron Institute Collection. *Hindwing*, Specimen No. 5389a (Fig. 5) in Yale University Collection, with counterpart No. 5389b in Cawthron Institute Collection.

Forewing.—Length 6.7 mm.; greatest breadth 1.9 mm.; ratio of length to breadth 3.5. This fine species differs from all others in the marked color-pattern, which consists of a band of pigment of medium depth passing transversely, and a little obliquely, across the wing from the pterostigma to the areola postica as an irregular fascia, and then running either continuously or with slight interruption or irregularity right back to the base along the posterior margin. Sc ends up in a fork a little distad from the level of the origin of Rs, well before half-way. The areola postica is rather flat, and Cu_{1a} may be connected with M_{3+4} by one or two cross-veins. Anal veins simple, but a cross-vein may be present between them. 1A runs very close to Cu_2 basally, but diverges from it distally. 2A slightly arched, diverging from 1A.

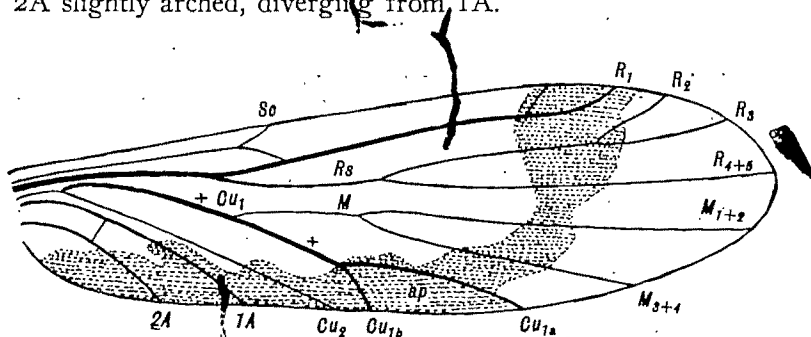


Fig. 7. *Delopsocus fasciatus*, n. gen. et sp. Forewing. Length 6.7 mm. Specimen No. 5377. Note the convex Cu_1 , indicated by +. ap, areola postica.

Types.—*Holotype forewing*, Specimen No. 5377a (Figs. 6, 7) in Yale University Collection, with counterpart No. 5377b in Cawthron Institute Collection. *Paratype forewings*, Specimens No. 5376a, 5404, in Yale University Collection, No. 5376b in Cawthron Institute Collection.

No hindwings have been found which could be definitely associated with this species.

Delopsocus latus (Sellards).

(Figs. 8, 9.)

Forewing.—Length 6 mm.; greatest breadth 1.9 mm.; ratio of length to breadth 3.2. This species is characterized by the somewhat broader wing, with marked inbending of the posterior margin at Cu_2 ; by the markedly asymmetrical fork

of Sc, ending well before half-way, and by the sigmoidally curved 2A with short posterior branch or supporting veinlet. The form of the areola postica is somewhat variable, but tends to be deeper in this species than in the others. Pterostigma slightly shaded.

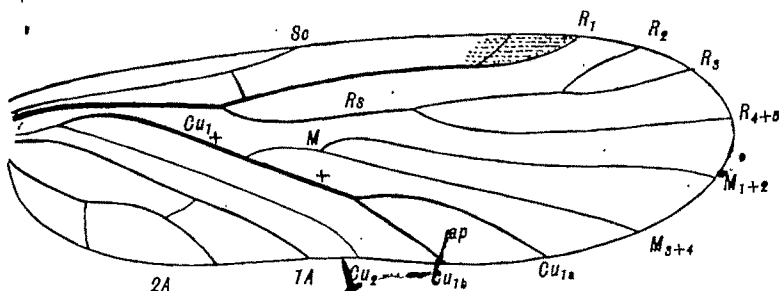


Fig. 8. *Delopsocus latus* (Sell.), n. gen. Forewing. Length 6 mm. Specimen No. 5379. Note the convex Cu_1 , indicated by +. ap, areola postica.

Hindwing:—Length 5.0 to 5.1 mm.; greatest breadth 1.7 mm.; ratio of length to breadth 2.9 or 3.0. Characterized by the very full anal area, with branched 2A. Rs, M and Cu all appear to come off close together just below R near base. Areola postica moderately deep, connected with M_{3+4} by a faint cross-vein.

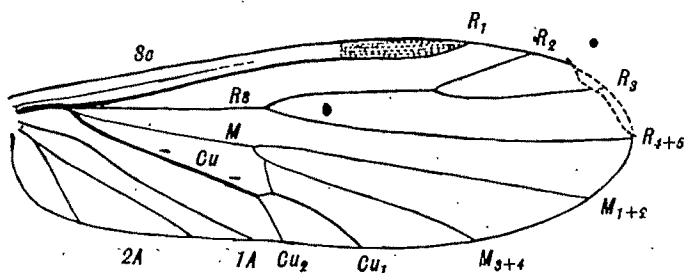


Fig. 9. *Delopsocus latus* (Sell.), n. gen. Hindwing. Length 5.1 mm. Specimen No. 5382. Note the concave main stem of Cu, indicated by —.

Abdomen (female) broad, shorter than wings; cerci very short, four-segmented.

Types:—*Holotype hindwing* (stated by Sellards to be a "front wing"), Specimen No. 94 in Sellards' Collection. *Paratypes:*—*Hindwing*, Specimens No. 5382a (Fig. 9), 5383 and

5401 in Yale University Collection, 5382b in Cawthron Institute Collection. *Forewings*.—Specimens No. 5379, 5380a, b, 5381a, 5390a-b, in Yale University Collection, Nos. 5378, 5381b in Cawthron Institute Collection. Specimen No. 5384a, in Yale University Collection, with counterpart No. 5384b in Cawthron Institute Collection, shows thorax, abdomen with cerci, complete right forewing, and portion of the other three wings.

Genus *Permembra*, n. gen.

(Figs. 10, 11.)

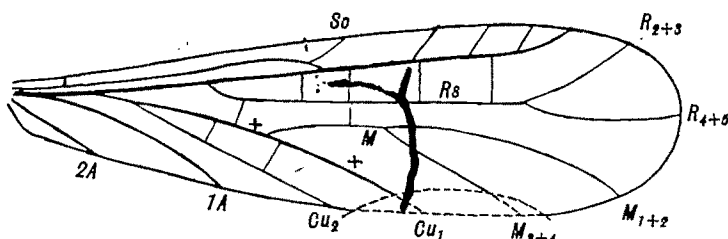


Fig. 10. *Permembra delicatula*, n. gen. et sp. Forewing. Length 2.3 mm. From Specimen No. 5403. Note the convex Cu_1 , indicated by +.

Head subglobular, with rather small, laterally placed compound eyes, antennae long, submoniliform, having thirteen or more segments, maxillary palpi prominent, probably five-segmented. *Thorax* with small prothorax, large and somewhat rectangular meso- and metathorax (these two segments being subequal) and very short legs placed far apart. *Abdomen* fairly long, cylindrical, with short, four-segmented cerci; male with somewhat asymmetrical terminal appendages. *Wings* very narrow basally; R_s only two-branched, M two-branched, Cu_1 simple; hindwing slightly shorter than fore, but similarly shaped. *Size* of insects very small.

Genotype.—*Permembra delicatula*, n. sp.

Horizon.—Lower Permian of Kansas.

Permembra delicatula, n. sp.

(Figs. 10, 11.)

Total length 3 mm.; *abdomen* 1.5 mm.; *forewing, length* 2.3 mm., *greatest breadth* 0.6 mm.; *ratio of length to breadth* 3.8.

The nearly complete specimen on which this species is based

is quite the smallest insect in the whole of the Yale University Collection, and it is surprising that such a delicate thing should have been preserved at all. Unfortunately the details of the venation are not very clear, the veins being very delicate even in the forewing. Attached to the head (Fig. 11, A) can be seen portions of both antennae, the one on the left showing at least thirteen segments including the swollen scape; the most distal of these does not appear to have been the terminal segment but was probably not far off. The forelegs (Fig. 11, A)

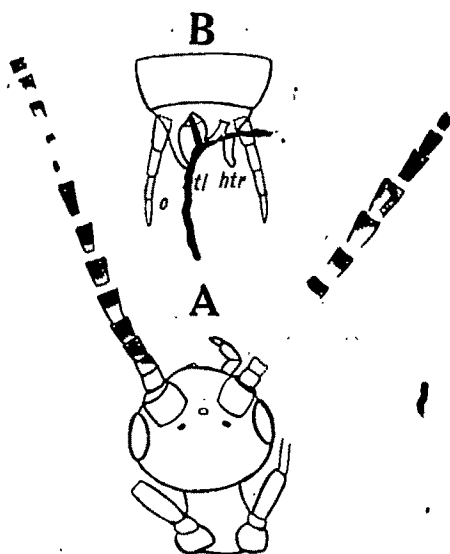


Fig. 11. *Permiania delicatula*, n. gen. et sp. A. Head, antennae and prothorax, from Specimen No. 5403 ($\times 48$). B. Anal appendages of male, from same specimen ($\times 48$). c, cercus; lhl, left, htr, right hemitergite of tenth abdominal segment.

show rounded coxa, small trochanter, short, fairly wide femur, and portion of a short tibia; unfortunately no part of the tarsus is preserved. The abdomen is only slightly narrower than the thorax, almost cylindrical, tapering slightly at the anal end; ten segments can be clearly made out. The cerci (Fig. 11, B) are only 0.3 mm. long, and consist of four subequal segments, the most distal of which is somewhat pointed. The other terminal appendages (Fig. 11, B) indicate that the specimen was a male, and suggest, by their asymmetry and form, a close relationship with the Embiaria. The tenth tergite appears

to be partially divided, the left hemitergite (Fig. 11, B, *htl*) carrying a somewhat hooked copulatory process, while the right hemitergite (Fig. 11, B, *htr*) carries a somewhat similar process and also a shorter one placed nearer the median line.

• *Wings*.—*Forewing* (Fig. 10) very narrowed basally, broadest at about three-fourths, apex well rounded. Costal space narrow, widening to pterostigma. Sc ending up a little before half-way by an asymmetrical fork, its connection with R_1 being stronger than that with the costa. Pterostigma long, with indications of weak veinlets. Rs arising at about one-third, forked distally, and connected with R_1 by a series of about four weak cross-veins. Cross-veins also indicated between Rs, Cu_1 and M, and between Cu_1 and Cu_2 . Fork of M considerably larger than that of Rs. M arising from Cu_1 well distad from level of origin of Rs. Cu_1 simple, ending somewhat beyond half-way along posterior margin. Cu_2 and anal veins simple, slightly diverging, 2A very short. *Hindwing*, as far as it can be made out, with venation similar to that of fore, but fork of Rs very small. Cubital and anal region of hindwing not clear.

Type.—Holotype, No. 5403a in Yale University Collection, with counterpart No. 5403b in Cawthron Institute Collection. This almost complete specimen has the right forewing extended at an angle of about 75 degrees to the body, the right hindwing lying between them but not showing up very distinctly; on the left side, the two wings lie together at an angle of about 30 degrees to the body.

Discussion of the Ordinal Position of the Family Delopteridae.

We are now in a position to consider the relationships of the family Delopteridae to other groups of insects, and to attempt to place them in their correct order. Making a survey of the characters of the family, I think we can say, without a shadow of doubt, that they are not Protorthoptera, and are not even closely related to any of that order or its allies, the Protoperlaria. The absence of MA and the anal fan of the hindwing proves this. We then have to ask, to what known orders do they show any resemblance? I think two orders only come into the question, viz. the Copeognatha and the Embiaria.

Relationship with the Copeognatha.—The relationship with this order comes through the Permian suborder Permopsocida

Tillyard, 1926, p. 318), and more especially through the family Psocidiidae and the genus *Dichentomum* Till. (l.c., p. 320, Fig. 3). Comparing the wings of *Delopsocus* (Fig. 7) and *Dichentomum*, we note the following points of resemblance:—the general shape, size, and texture, the short, forked Sc, the formation of the areola postica, and the form of Cu₂ and the anal veins. The outstanding differences are important; viz. that *Dichentomum*, in common with practically all Copeognatha of the present day, has only a two-branched Rs, and has also, in common with all Permian Copeognatha, a four-branched M, which becomes reduced to three branches in nearly all recent Copeognatha.

Martynov (1926) has argued that the three-branched condition of Rs is primitive, and that the Lower Permian Permopsocida must therefore be regarded as a specialized side-branch. He bases this opinion on the Jurassic genus *Archipsylla* (l.c., p. 1363, Fig. 8) which he describes as having a three-branched Rs. But his figure clearly shows that Rs in this species was actually only two-branched, and the vein which he labels R₂ is evidently R₁, bounding a more than usually deeply looped pterostigma, and connected with the true Rs by a hypostigmatic cross-vein which he takes to be the basal piece of R₂. *Archipsylla* has a four-branched M, and is rightly placed in the Permopsocida, of which it is a Jurassic remnant. We can see from this that the two-branched Rs is primitive for the whole order of Copeognatha (*s. str.*). This two-branched condition is shown also, exactly, in *Permembia*, n. gen. (Fig. 10), but otherwise the Delopteridae have Rs three-branched.

As regards body-structure, unfortunately only the new genus *Permembia* is at all complete. But we have one female specimen of *Delopsocus latus* (Sell.) in which the abdomen and cerci are complete (No. 5384). From this we gather that the body was much as in the Psocidiidae, rather short, stout in the female, and with short, four-segmented cerci.

The really outstanding difference between Delopteridae and all true Copeognatha, as well as, apparently, all other insects, is the extraordinary condition of the cubitus of the hindwing. In attempting to correlate these insects with any other order, this character must be given due consideration.

Relationships with the Embiaria.—Here we naturally make the comparison between *Permembia*, n. gen., and the Embiaria proper. We note at once the general Embiarian form of the body, including the head, antennae, thorax, abdomen and cerci,

though the latter are reduced to two segments in the true Embiaria. The short legs, placed far apart, are also very Embiarian in form, but, most unfortunately, no sign of the tarsus can be found in the fossils, so that we do not know whether

the striking character of the swollen fore tarsus was present or not. In the wings, the general weakness of all the venation except only R_1 and Cu is strikingly suggestive of the even more reduced condition of the venation found in true Embiaria, and the beginnings of weak cross-veins are also comparable with those of Embiaria. But, as regards the details of venation, I do not see how they can be brought into line unless our present interpretation of the limits of the main veins in Embiaria is wrong. Comstock (1918, p. 263, Fig. 260) shows the tracheation of a wing of the nymph of *Embia*, after Melander, which is strikingly like the venation of *Permembia* in that it has both Rs and M two-branched; but other species of *Embia* appear to have M simple, while the supposedly most primitive genera *Clothoda* and *Donaconethis* have Rs three-branched, with the extra branch on R_{4-5} . In general texture and chaetotaxy the wing of *Permembia* is not Embiid-like, but Copeognathous.

The conclusion which I come to, on the above comparisons, is that the family Delopteridae does not lie in the direct ancestral line of any existing group. It has some relationships with the Embiaria, and some with the Copeognatha; of all known insects, it is certainly closest to the family Psocidiidae of the suborder Permopsocida of the Copeognatha, and is more especially close to the genus *Dichentomum* Till., already recognized as the most primitive of all known Copeognatha. I therefore propose that the group be retained for the present as a special side-branch of the order Copeognatha, probably equivalent in value to the Zoraptera, and suggest the name Embiopsocida for the group, to be regarded for the present as of subordinal value only.

The presence of these old groups having fore and hind wings of similar shape, without any anal fan, and with no development of MA, raises the wider question of the origin of the Holometabola. Apart from the fewer branches of Rs and M, the general scheme of venation in these forms is not unlike that of the Mecoptera and also of the Coniopterygidae amongst the Neuroptera. It is possible that the Holometabola actually came from very small ancestors not unlike the Permopsocida in general organization, but the present-day relationships between Copeognatha and Holometabola must be exceedingly slight.

Addendum.—Specimens No. 5395a-b, 5396 and 5398 (hindwing), all in the Yale University Collection, belong to the family Delopteridae, but cannot be placed with any certainty in their correct genera and species.

Note on the genus Urba Sell.—Sellards (1909, p. 169) described "*Urba punctata* gen. et sp. n." at the end of the family Delopteridae. His description of four lines is quite inadequate, the only characters given for both genus and species being the "slender elongate anal area traversed by three of four veins" and the wing membrane with "a punctate appearance, due probably to the presence of short spines bordering the veins". The fore wing is stated to be 9 mm. long by 3 mm. wide. Unfortunately he gave no figure, and Mr. Carpenter tells me that the type (Sellards' No. 1117) is lost. It would be impossible to say anything of this genus except that it obviously does not belong to the family Delopteridae.

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CORRELATION OF THE UPPER CRETACEOUS OR GULF SERIES OF THE GULF COASTAL PLAIN.*

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GENERAL CHARACTER AND DISTRIBUTION.

The Upper Cretaceous or Gulf series consists chiefly of sand, clay, marl, chalk, limestone, and subordinately of gravel, and outcrops in a belt which, with certain interruptions due to the overlap of younger formations, extends approximately parallel to the inner edge of the Atlantic and Gulf Coastal Plain from Mexico to Marthas Vineyard, Mass. The belt attains its greatest width of over 100 miles in the region of Cape Fear River valley in North Carolina, and, information received since the accompanying correlation chart (Fig. 1) was drawn, indicates that the series reaches a maximum thickness of 3,500 feet or more in the Rio Grande valley in Texas.

The series is predominantly composed of marine sediments which were deposited in the ocean at depths ranging from a few feet in the shallow near-shore waters to probably not more than 600 feet (100 fathoms) in the off-shore waters. Some of the sediments were, however, laid down in coastal lagoons and estuaries, and some on the alluvial flood plains of streams. The beds composing the middle and upper parts of the series are in general finer and more uniformly of the deeper water type than those composing the lower part, which are coarser and more irregularly bedded. Sediments of shallow water origin are, however, not wanting in the middle and upper parts of the series, as in places in Georgia and Alabama. The fact that the deposition of many of the formations of the Gulf series began after periods of erosion without the introduction of conspicuous amounts of coarse materials into the sea to form basal conglomerates, indicates that low-lying lands were the source of the sediments.

The succession of formations which make up the series differs markedly from place to place along the linear extent of the Coastal Plain, so that many columnar sections are required

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to completely represent the sequence of formations, and the age relations of the formations to each other.

The major divisions of the standard geological column of the Upper Cretaceous of Europe, with one exception, are represented in the Gulf series of the Atlantic and Gulf Coastal Plain. These are, in ascending order, Cenomanian, Turonian, and Senonian. If the Danian, which in Denmark overlies the Senonian, is represented in the Coastal Plain, it must be in the basal beds of the Eocene and not in the Cretaceous. In this connection it may be stated that the Cretaceous age of the Danian has not been established to the satisfaction of all even of the European stratigraphers. Although there are obviously certain close relationships between the fossil organisms of beds of corresponding age on opposite sides of the Atlantic, few species, especially among the molluscan invertebrates, are identical, and the correlations indicated on following pages should be regarded as tentative and subject to revision as new evidence is obtained.

Even in the Coastal Plain itself the age relations of the formations in the different parts of the area are not all established with finality and it is unwise to state with dogmatic assurance the age equivalence of beds more or less distant from each other, unless the evidence is very strong. Hasty conclusions based on insufficient evidence may introduce errors that will be quoted and requoted for years before they are corrected. The correlations of the lower formations of the series are based in part on fossil plants and in part on marine invertebrates; fossil plants, studied chiefly by Prof. E. W. Berry, have been the basis for the age determination of the Tuscaloosa formation of the eastern Gulf region, the Middendorf formation of South Carolina, and the Raritan formation of Maryland, Delaware, and New Jersey. The correlations in the middle and upper parts of the series are made chiefly on the evidence of marine invertebrates.

The part of the series corresponding in age to the Senonian includes two major fossil zones which have been differentiated practically throughout the length of the Atlantic and Gulf Coastal Plain. These are the *Exogyra ponderosa* zone, which probably roughly corresponds to the Santonian and Campanian subdivisions of the Senonian, and the *Exogyra costata* zone, which is referred to the Maestrichtian or upper Senonian. A more restricted zone, the *Exogyra cancellata* zone, in the lower part of the *E. costata* zone, is traceable from New Jersey to central Texas.

The standard Upper Cretaceous (Gulf) section of central Texas, as established by the pioneer geologists of the region, includes from the base upward, the Woodbine sand, the Eagle Ford clay, the Austin chalk, the Taylor marl, and the Navarro formation. These divisions are still the recognized formation units of central Texas, but both toward the southwest and the northeast they pass more or less completely into contemporaneous sediments of such different character as to necessitate their subdivision into different sets of formations.

The relative thinness of the Gulf series in central Texas, as compared with its much greater thickness in both the East Texas embayment and the Rio Grande embayment (see Fig. 1), clearly records the effect of the Llano uplift, where repeated oscillations caused emergence and erosion from time to time during the upbuilding of the series.

In the western Gulf region the Upper Cretaceous (Gulf) series rests with a marked unconformity upon the Lower Cretaceous (Comanche) series. In the north Atlantic the Upper Cretaceous rests unconformably upon the Potomac group of the Lower Cretaceous series, a group which is of nonmarine origin and whose correlation is based upon fossil plant and vertebrate remains. In the Mississippi Embayment, the eastern Gulf region, and the south and middle Atlantic region, where the Lower Cretaceous is wanting, a great hiatus separates the Upper Cretaceous from underlying rocks of pre-Paleozoic and Paleozoic age, and to a very limited extent of Triassic age. Throughout the Coastal Plain the Upper Cretaceous series is unconformably overlain by strata of Eocene or later age.

The Woodbine Sand.

The Woodbine sand consists of a maximum of 500 feet or more of irregularly-bedded sand, clay, and some lignite, of shallow marine, brackish water, and subordinately of non-marine origin. The formation rests unconformably on the Comanche series and is probably unconformably overlain by the Eagle Ford clay. The formation is in part fossiliferous, especially in the higher layers.

The Woodbine formation thins toward the south and pinches out in central Texas along the eastern side of the Llano uplift. Toward the north and northeast the formation has been traced through northeastern Texas and southeastern

Oklahoma into southwestern Arkansas. It has not been recognized east of Mississippi River, but it may be represented in the Tuscaloosa formation of Alabama. However, Prof. E. W. Berry, who has studied the fossil plants from the Tuscaloosa, has not recognized the Cenomanian age of any part of that formation, the correlation of which must depend chiefly on fossil plants.

The superposition of the Woodbine formation on the Comanche series, whose uppermost part is of either upper Albian or lower Cenomanian age, and the occurrence of several species of ammonites related to *Acanthoceras rotomagensense* (Defrance), in the base of the overlying Eagle Ford formation, determines the Cenomanian age of the Woodbine. This correlation has been published by Dr. Gayle Scott and confirmed by Drs. T. W. Stanton and J. B. Reeside. The Woodbine formation is younger than any part of the Comanche series and is separated from that series by a pronounced unconformity.

Eagle Ford Clay and Equivalent Beds.

The Eagle Ford clay consists of 30 to 500 feet of dark more or less bituminous shaly clay with interbedded flaggy limestone, of marine origin. The formation is believed to rest with unconformable relations upon the Woodbine sand. In central and northeastern Texas it is separated from the overlying Austin chalk by an unconformity, but the continuation of this unconformity westward to the Rio Grande has not yet been demonstrated.

The formation is 500 feet thick in the east Texas embayment, thins to a minimum of 30 feet where it flanks the south side of the Llano uplift, and thickens again to at least 250 feet in the Rio Grande embayment.¹ Eastward in northeastern Texas where the Upper Cretaceous beds are partly concealed by alluvium of Red River, of Pleistocene age, the Eagle Ford seems to disappear as such, but paleontologic evidence indicates that it may be represented there in Woodbine-like sediments. The formation appears to be wanting in Arkansas. It may be represented in the shallow-water Tuscaloosa formation of Alabama, which is barren of marine invertebrate fossils; it may also be represented in the Middendorf

¹ Reports of thicknesses as great as 500 and 600 feet in wells in the Rio Grande valley have been received.

formation of South Carolina and in the "Cape Fear" formation of North Carolina.

As previously stated, the base of the typical Eagle Ford clay yields a fauna, characterized by several species of ammonites related to *Acanthoceras rotomagense*, which indicate its Cenomanian age. The Turonian age of the remainder of the formation above this basal zone is indicated by the ammonite genera, *Metoicoceras* (several species) in the lower part of the formation above the *Acanthoceras* zone, *Prionotropis* in the middle, and *Prionocyclus* in the upper part of the formation. *Prionocyclus* has not been found in the outcropping beds but has been identified in a stratum of upper Eagle Ford age in a deep well in DeSoto Parish, Louisiana. This correlation of the Eagle Ford clay is in harmony with the conclusions of several paleontologists who have critically studied the ammonites, including Doctors Stanton, Reeside, Scott, and others. The Turonian age of the Eagle Ford is also indicated by the bivalve species, *Inoceramus labiatus* Schlotheim, a world-wide Turonian index fossil, whose range in Texas appears to be through the zones of *Metoicoceras* and *Prionotropis*.

Austin Chalk and Equivalent Beds.

The Austin chalk typically consists of 400 feet or more of thick to massive-bedded chalk and subordinate interbedded chalky marl, of marine origin. The formation is well developed from the Rio Grande, northeastward through Texas nearly to the valley of Red River in Grayson County. In central and northeastern Texas the chalk and its equivalents are separated from the underlying Eagle Ford clay by an unconformity. In central Texas as far north as the northern part of Ellis County the Austin and Taylor appear to be unconformable, but from Dallas County northward the upper part of the chalk seems to transgress upward in the geologic column so that in Collin and Grayson counties the upper part of the chalk is probably of the age of the lower part of the typical Taylor marl farther south. From Grayson County eastward part of the Austin chalk merges into nonchalky equivalents, so that in Lamar County the section corresponding to the expanded part of the chalk farther west would include in ascending order the Bonham clay, the Blossom sand, the Brownstown marl, and the Gober tongue of the Austin chalk, all of which are typical marine sediments. Of these the Bonham and Blossom corre-

spond in age to the typical Austin chalk of central Texas, and the Brownstown and Gober correspond to the basal part of the typical Taylor.

The Eagle Ford clay appears to have no representative in Arkansas, and the Tokio formation, composed of sand, clay and gravel immediately overlying the Woodbine, appears to be the shallow marine representative of the Bonham clay and Blossom sand, and therefore of the typical Austin chalk.

In the eastern Gulf region the Austin is probably represented in part at least by the marine shallow-water sands and clays composing the part of the Eutaw formation below the Tombigbee sand member, although there is no direct invertebrate fossil evidence for this correlation. There is paleontologic evidence, however, that the upper part of the Eutaw, the deeper-water Tombigbee sand member, is a little younger than the upper part of the typical Austin. The Austin may be represented in the lower part of Black Creek formation of the Carolinas and in the Magothy formation of Maryland, Delaware, and New Jersey.

The typical Austin chalk is considered to be the American representative of the lower part of the Senonian of Europe including the Coniacian and the lower part of the Santonian subdivisions. The direct paleontologic evidence consists of the common occurrence of *Inoceramus undulato-plicatus* Roemer in the Coniacian and in the middle and upper parts of the Austin, and of *Mortoniceras texanum* Roemer in the lower part of the Santonian and in the upper part of the Austin. The Austin also contains species of *Inoceramus* having the shell elongated parallel to the hinge line, unlike any of the species of that genus in the Turonian and older beds.

Taylor Marl and Equivalent Beds.

The Taylor marl of central Texas is typically composed of 500 feet or more of calcareous clay and marl of marine origin, with sandy and chalky facies, the more conspicuous of which, as determined by C. H. Dane and me,¹ have been named Durango sand member, Lott chalk member, and Marlin chalk member. The formation in central Texas rests unconformably upon the Austin chalk and is overlain probably uncon-

¹ Dane, C. H., and Stephenson, L. W., Notes on the Taylor and Navarro formations in east-central Texas: Bull. Am. Assoc. Petr. Geologists, 12, No. 1, 41-58, 1928.

formably by the Navarro formation. Westward in Texas the Taylor marl is replaced by the Anacacho limestone, a formation composed of impure shallow marine limestone and interbedded marl, and still farther west in the Rio Grande Valley the Anacacho is represented by the Upson clay and the overlying San Miguel formation. Toward the north in central Texas the unconformity which separates the Taylor from the underlying Austin chalk appears to die out and the chalk expands in such a manner that its upper part is equivalent in age to the lower part of the Taylor marl farther south. Farther toward the northeast the typical Taylor is represented by the Brownstown marl, the Gober tongue of the Austin chalk, and typical marl in which are interbedded the Wolfe City sand member and the westward-extending Pecan Gap tongue of the Annona chalk. Still farther toward the east the Taylor is represented by the Brownstown marl and the Annona chalk.

The equivalents of the typical Taylor in Arkansas are in ascending order the Brownstown marl, the Ozan formation, the Annona chalk, and the Marlbrook marl; these are all of marine origin.

East of Mississippi River in Tennessee and northern Mississippi the typical Taylor is represented by the shallow-water marine Coffee sand member of the Eutaw formation and the lower part of the deeper marine Selma chalk of that area. In east-central Mississippi and in west-central Alabama the section of Taylor age includes probably the Tombigbee sand member of the Eutaw formation and approximately the lower two-thirds of the overlying Selma chalk. Farther east in the Chattahoochee region (Alabama-Georgia) the corresponding section includes the Tombigbee sand and the lower part of the Ripley formation of that area. The Taylor is represented at least in part by the upper part of the Black Creek formation of the Carolinas, and by the Matawan formation of Maryland, Delaware, and New Jersey.

Probably the most outstanding fossil which ties the formations of Taylor age together throughout the Atlantic and Gulf Coastal Plain is *Exogyra ponderosa* Roemer. Although in Texas this species ranges downward into the upper part of the underlying Austin chalk, it does not range upward into the overlying Navarro formation. The Taylor and its equivalents therefore constitute the major part of the zone of *Exogyra ponderosa*. Numerous other fossil forms, some of

which have been found for only limited distances along the trend of the major zone, afford confirmatory evidence of the correctness of the correlation, but the details of this evidence can not be stated within the scope of this paper.

As nearly as can be determined with the present available evidence (the Taylor marl finds its European equivalent in the middle part of the Senonian, including the upper part of the Santonian and probably all of the Campanian sub-divisions. The evidence is somewhat indirect so far as the typical Taylor is concerned. *Scaphites hippocrepis* Morton, for example, as identified by Dr. J. B. Reeside, is common to the lower part of the Anacacho limestone of Texas, the lower part of the Brownstown marl of Arkansas, and the Merchantville clay of New Jersey, all of lower Taylor age, and to the Santonian of Europe. Especially significant is the occurrence in the Tombigbee sand of Mississippi, which is probably of lower Taylor age, of the stemless free-floating crinoid, *Marsupites americanus* Springer, which, according to Springer, is very closely, perhaps specifically, related to *Marsupites testudinarius* Schlotheim of the Santonian of Europe. Additional evidence of the approximate correctness of this trans-Atlantic correlation is afforded by the common occurrence of ammonites related to *Mortoniceras delawarensense* (Morton) and of species of the bivalve *Inoceramus* of the *I. baribini* Morton type.

The Navarro Formation and Equivalent Beds.

The Navarro formation of central Texas is composed of 400 to 600 feet of marine clay, marl, and sand more or less glauconitic, and the formation is believed to rest unconformably upon the Taylor marl throughout most of its extent. In the Rio Grande region the lower part of the Navarro is represented only by the sediments of the nonmarine Olmos formation, or "coal series," and the middle and upper parts are represented by the Escondido formation, the uppermost beds of which may be somewhat younger than the youngest beds of the Navarro. In Arkansas the Navarro equivalents include the Saratoga chalk, the Nacatoch sand, and the Arkadelphia marl. In northern Mississippi the upper part of the Selma chalk and the Ripley formation are the approximate equivalents of the Navarro formation, but farther north these deposits are largely represented by the shallow water McNairy sand member of the Ripley, which extends through Tennessee

and Kentucky to the head of the Mississippi embayment; strictly marine deposits of lower Navarro age at the head of the embayment are indicated by the finding of *Exogyra cancellata*. Stephenson in an excavation for a bridge pier near Cairo, Illinois. In east-central Mississippi and west-central Alabama the Navarro equivalent is found in the upper part of the Selma chalk and in the Chattahoochee region (Georgia-Alabama) in the upper part of the Ripley formation of that area.

Exogyra costata Say is a widespread and useful index fossil in the Navarro formation and its equivalents in the Coastal Plain, and for this reason the name *Exogyra costata* zone has been applied to the deposits. Non-typical specimens of the species are, however, occasionally found below the zone proper. Another species of the same genus, *Exogyra cancellata*, forms a more restricted zone in the lower part of the *Exogyra costata* zone. The *E. cancellata* zone is traceable in the Atlantic and Gulf Coastal Plain with certain interruptions from New Jersey to Milam County, Texas, a distance of fully 2,000 miles, beyond which toward the Rio Grande the *cancellata* zone appears to be wanting and is represented by the unconformity between the Taylor and Navarro formations and their equivalents. The range of *Exogyra cancellata* is also not closely restricted to the zone to which the name has been applied, for in Arkansas fairly typical specimens of the species occur in the uppermost part of the underlying *Exogyra ponderosa* zone, and in Tennessee the occurrence of the species in the Coon Creek fauna of the lower Ripley indicates a somewhat higher range than it is known to have elsewhere in the Coastal Plain.

The upper part of the Navarro formation and its age equivalents from central Texas in the western Gulf region to Georgia in the eastern Gulf region carries a large number of identical and closely related species of mollusks which are absent or rare in the underlying zone of *Exogyra cancellata*. Some of the more conspicuous and useful of these are:

Trigonia eufaulensis Gabb	Aphrodina tippiana Conrad
Pulvinites argentea Conrad	Turritella vertebroides Morton
Crenella serica Conrad	Sargana stantoni (Weller)
Pholadomya littlei Gabb	Morea cancellaria Conrad
Dreissensia tippiana Conrad	Liopeplum lioderium (Conrad)
Liopistha protexta Conrad	Ringicula pulchella Shumard
Crassatellites subplana (Conrad)	Scaphites conradi Morton (including several varieties)
Cardium stantoni Wade	Sphenodiscus (several species)
" tippanum Conrad	Belemnites americana (Morton)
" dumosum Conrad	
" kummeli Weller	

In the Carolinas the Peedee formation is clearly the equivalent of the Navarro, and in the north Atlantic region the Navarro is represented by the Monmouth group. These correlations are confirmed by the common occurrence of numerous fossils of restricted range.

The upper third or so of the *Exogyra costata* zone is characterized by a varietal form of *Exogyra costata* with narrower and weaker costae than those of the more typical shells in the middle and lower parts of the zone. This variety occurs in the uppermost part of the Navarro formation in Texas, in the Arkadelphia clay of Arkansas, in the upper parts of the Ripley and Selma formations in the eastern Gulf region, and in the upper part of the Peedee formation of the Carolinas.

The Escondido formation, which has its fullest development from Medina County, Texas, to the Rio Grande, is the time equivalent of the middle and upper parts of the typical Navarro formation, and carries a molluscan fauna which differs in many important respects from that of the Navarro. This is due in part at least to the different environmental conditions which existed in the Escondido sea, for the formation was laid down in shallower marine waters of the Rio Grande embayment which were receiving a greater bulk of sediments than was the Navarro sea. However, the lower part of the Escondido is tied to the middle part of the Navarro and equivalent beds by *Exogyra costata*, *Pecten venustus* Morton, and a few other forms. Closely related species of the genus *Sphenodiscus* are common to the two formations, and this genus ranges to the top of the Escondido.

The Navarro formation and its equivalents are believed to be approximately of the age of the Maestrichtian, the uppermost division of the Senonian of Europe. The most direct evidence of the correctness of this correlation is afforded by the ammonite genus *Sphenodiscus* which is common to the upper part of the Navarro and to the Maestrichtian, and by a species of the ammonite genus *Pachydiscus*, related to *P. gollvillensis* D'Orbigny (identified by J. B. Reeside), found in the lower part of the Escondido formation; the latter species occurs in the Maestrichtian of Europe. The same correlation is suggested by the occurrence in the Maestrichtian of *Belemnitella mucronata* D'Orbigny, an analogue of *B. americana* (Morton). The reference of the lower part of the Navarro, the *Exogyra cancellata* zone, in which *Sphenodiscus* has not been found, to the Maestrichtian, rather than to the upper Campanian, may be open to question, but it is tentatively

regarded as lower Maestrichtian until further evidence is obtained.

The approximate age equivalents in the Western Interior of the standard Upper Cretaceous section of Texas have long been approximately known, but the continued studies of Doctors Stanton and Reeside have resulted in the recognition in the latter province of several restricted fossil zones which correspond quite closely with similar zones in the former province.

The Woodbine sand is correlated with the Dakota sandstone, using that name as applied to the basal sandstones of the Upper Cretaceous below the typical Benton shale. In south-central Colorado a zone of *Acanthoceras* aff. *A. rotomagensis* is now recognized in the Graneros shale, a formation of lower Benton age. The same zone is found in a similar position near the base of the Mancos shale in west-central Colorado. It would appear, therefore, that the lower Benton is of Cenomanian age. In the beds of Benton age above the *Acanthoceras* zone have been recognized a *Metoicoceras* zone, followed at a higher level by a *Prionotropis* zone, and at a still higher level by a *Prionocyclus* zone. It would appear therefore that the Benton formation and its equivalent beds in the Western Interior, like the Eagle Ford clay, include a basal zone of Cenomanian age, though they consist chiefly of rocks of Turonian age as has been generally accepted. *Inoceramus labiatus* Schlotheim and *I. fragilis* Hall and Meek are common to the Eagle Ford and to the Benton. In the Eagle Ford *I. fragilis* occurs more abundantly in the *Metoicoceras* zone and *I. labiatus* more abundantly in the *Prionotropis* zone; in the Benton and its equivalents the reverse seems to be true. Probably the two species range through both of these zones. *Ostrea lugubris* Conrad occurs in a zone at the top of the Eagle Ford, and also in a zone of upper Benton age in New Mexico and southern Colorado.

The Austin chalk appears to be approximately contemporaneous with the Niobrara limestone and its equivalents, a correlation heretofore generally accepted, and this age assignment is directly indicated by the presence in the Niobrara of *Inoceramus deformis* Meek and *I. undulato-plicatus* Roemer, and the occurrence of the upper Eagle Ford species *Ostrea lugubris* just below the Niobrara in southern Colorado, and in the bed of upper Benton age in New Mexico to which reference has just been made.

The Taylor marl of the Gulf region lies between the Austin chalk below and the Navarro formation above, and the Pierre shale of the Western Interior (Colorado, Wyoming, and adjacent States) lies between the Niobrara below and the Fox Hills sandstone above. The Pierre and Taylor must therefore be of approximately the same age, but the uppermost Pierre may be a little younger than the uppermost Taylor, and therefore of lower Navarro age. Certain faunal elements in the Eagle sandstone (of lower Pierre age) such as *Scaphites hippocrepis* Morton, *Mortoniceras delawarensis* (Morton) and *Inoceramus* aff. *I. sagensis* Owen, tend more directly to tie the lower Pierre to beds of lower Taylor age. In the middle Pierre faunas of Utah, Colorado, and southern Wyoming, a considerable number of species closely related to those of upper Taylor age afford another tie.

As nearly as can be determined with the available evidence, the part of the Navarro formation above the *Exogyra cancellata* zone corresponds in age to the Fox Hills sandstone of the Western Interior. This correlation is indicated by the occurrence in the Fox Hills of a group of ammonites of the genus *Scaphites*, which are closely related to *Scaphites conradi* Morton and to one or two of its varieties in the upper Navarro and equivalent beds, and in the common occurrence of the ammonite genus, *Sphenodiscus*; the latter genus did not make its appearance in either the Atlantic and Gulf Coastal Plain, the Western Interior, or Europe, until late in Upper Cretaceous time.

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THE RELATIVE AGES OF THE IOWAN AND ILLINOIAN DRIFT SHEETS.

GEORGE F. KAY.

INTRODUCTION.

The most generally recognized classification of the Pleistocene of the Mississippi Valley includes five glacial stages and four interglacial stages. The glacial stages, from the oldest to the youngest, are the Nebraskan, the Kansan, the Illinoian, the Iowan, and the Wisconsin stages; the interglacial stages, in the same order of age, are the Aftonian, the Yarmouth, the Sangamon, and the Peorian stages.

From time to time within the last twenty years, doubt has been expressed by some students of the glacial deposits as to whether or not there is sufficient evidence to justify the continuance of the recognition of the Iowan glacial stage. If not, the classification of the Pleistocene in America would include not five but four glacial stages. Moreover, if the deposits which have been considered to belong to the Iowan glacial stage can be shown to have been deposited during a late part of the Illinoian glacial stage, as has been suggested recently by Leverett,¹ then again our classification would include only four glacial stages.

It is the purpose of this paper to restate the evidence which has been given in support of the existence of an Iowan drift sheet in Iowa and to present evidence in addition to that which has been presented by other geologists to prove that the Iowan drift sheet should not be correlated with the Illinoian drift sheet. The new evidence in favor of the interpretation that the Iowan glacial stage was an independent stage from the Illinoian is the presence of a widespread weathered loess which is post-Illinoian, pre-Iowan in age.

As a background for a proper understanding of the discussions of the Iowan and Illinoian drifts, brief statements will be made regarding the development of our present knowledge of these drifts and of closely associated glacial and interglacial deposits.

¹Leverett, Frank, The Pleistocene Glacial Stages: Were There More Than Four? Proc. Am. Phil. Soc., 65, No. 2, 1926.

McGee's Upper Till and Lower Till.

Previous to 1880 McGee had found evidence of two tills in northeastern Iowa, and in 1881, he² referred to them as the upper till and the lower till, each having its own distinctive characteristics. In some places his upper till was the surface till and in other places the lower till was at the surface. He was able to map both the tills areally. Where both tills were present in a section they were separated, in many places, by a forest bed or its stratigraphic equivalent, "hardpan", or "gumbo", which he stated was the modified upper portion of his lower till. At this time, McGee interpreted the widespread loess of northeastern Iowa as being equivalent in age to his upper till. In his final report on northeastern Iowa, based upon investigations which extended over many years, McGee³ described in detail the topographic and lithologic character, the stratigraphic relations, and the geographic extent of his Upper Till and his Lower Till. He pointed out that his Upper Till was younger than the gumbo-surfaced drift (present Kansan drift) of southern Iowa, and older than the till of the Des Moines lobe (present Wisconsin drift). McGee did not differentiate in northeastern Iowa a third drift (present Nebraskan drift) which has no mappable surface distribution within his area but which has been exposed in a few places within his area, in railroad cuts and in road cuts, and has been penetrated in well drillings.

The Names Kansan and Iowan.

About the year 1895 the names Kansan and Iowan, which were given first to two tills in the Afton Junction region in southwestern Iowa and which were thought to be the equivalents of McGee's Lower and Upper tills, respectively, were applied to these tills in northeastern Iowa. These names have continued to be used for the two surface tills of McGee's area in northeastern Iowa. There has been some question with regard to the propriety of the names Kansan and Iowan for these two tills but it would serve no useful purpose to enter into a discussion of that question here. This paper deals chiefly with the characteristics and relationships of the till of

² McGee, W J, The Relations between Geology and Agriculture: Iowa Horticultural Soc., Trans., 16, 227-240, 1881.

³ McGee, W J, The Pleistocene History of Northeastern Iowa: U. S. Geol. Surv. 11th Ann. Rept., 195-568, 1891.

northeastern Iowa which has been called Iowan and of the Illinoian till of southeastern Iowa.

Illinoian Drift Sheet Discovered.

In 1895 Chamberlin⁴ presented a classification of the glacial deposits of the Mississippi Valley in accordance with the best evidence of that time. Here he included the Illinoian till sheet which had been determined by Leverett to be the product of an ice invasion into southeastern Iowa from the east at some time between the Kansan glacial epoch and the Iowan glacial epoch. In this paper Chamberlin gave a system of time ratios based upon his impression of the relative amounts of erosion and weathering of the drifts. With regard to the Iowan and the Illinoian, he stated that if the time since the close of the Wisconsin is taken as one unit, then the time since the Iowan would be represented by five units and since the Illinoian in Iowa by eight units.

Leverett's Yarmouth, Sangamon, and Peorian.

In 1898 the names Yarmouth, Sangamon, and Peorian were introduced into the classification of the Pleistocene deposits in the Mississippi Valley by Leverett.⁵ The name Yarmouth was applied to the soil and weathered zone at the junction of the Illinoian and the Kansan till sheets in the region of overlap between Davenport, Iowa, and Quincy, Illinois. Leverett stated: "The presence of this soil horizon was first brought to the writer's notice by a well section at Yarmouth in Des Moines county, Iowa. For this reason and because the name of this village is less likely to be confusing than names which are common, it seems appropriate to apply the name Yarmouth to this weathered zone. There is also at Yarmouth not only a soil horizon but apparently a pronounced erosion between the Illinoian and Kansan sheets."

The name Sangamon was applied to the soil horizon between

⁴Chamberlin, T. C., The Classification of American Glacial Deposits: Jour. Geol., 3, 270-277, 1895.

⁵Leverett, Frank, The Weathered Zone (Yarmouth) between the Illinoian and Kansan Till Sheets: Jour. Geol., 6, 238-243, 1898; Proc. Iowa Acad. of Sci., 5, 81-86, 1898.

The Weathered Zone (Sangamon) between the Iowan Loess and Illinoian Till Sheet: Jour. Geol., 6, 171-181, 1898; Proc. Ia. Acad. of Sci., 5, 71-81, 1898.

The Peorian Soil and Weathered Zone (Toronto formation?) Jour. Geol., 6, 244-249, 1898.

the Illinoian till sheet and the Iowan loess. The first recognition of the occurrence of this definite soil horizon was reported by A. H. Worthen. In his report on Sangamon county, Illinois, made in 1873, he called attention to a soil found at the base of the loess in Sangamon and neighboring counties. The name Sangamon was taken from this locality where the soil was first reported.

The name Peorian was applied to the weathered zone at the contact between the Iowan loess, which was correlated with the Iowan till, and the Wisconsin till in the region of Peoria, Illinois. In an exposure east of Peoria, there was evidence of an interval between the deposition of the loess which was correlated with the Iowan till and the Shelbyville till sheet, which appeared to be the earliest of the Wisconsin series.

The Illinois Glacial Lobe.

In 1899 Leverett's monograph⁶ on the Illinois Glacial Lobe appeared. In this publication his new terms were used in connection with the classification of the Pleistocene deposits of the Mississippi Valley. The classification given is as follows, from the oldest to the youngest:

(1) Oldest recognized drift sheet, Albertan of Dawson, and sub-Aftonian of Chamberlin; (2) Aftonian; (3) Kansan drift; (4) Yarmouth interval; (5) Illinoian drift; (6) Sangamon interval; (7) Iowan drift and main loess deposit; (8) Peorian, possibly equivalent to Toronto of Chamberlin; (9) Early Wisconsin morainic drift; (10) unnamed interval shown by shifting of ice lobes; (11) Late Wisconsin morainic drift; (12) (13) (14) and (15) stages of Lake Chicago as given in an earlier publication.

Students of glacial deposits in Iowa and adjacent states were at this time agreed that there was evidence of five distinct ice invasions, the Albertan or sub-Aftonian, the Kansan, the Illinoian, the Iowan, and the Wisconsin; and that there were four distinct interglacial epochs, the Aftonian, the Yarmouth, the Sangamon, and the Peorian.

The Iowan Drift Described by Calvin.

In 1899 Calvin⁷ published a paper in which he described fully the features of the Iowan drift of northeastern Iowa. It is

⁶ Leverett, Frank, *The Illinois Glacial Lobe*: U. S. Geol. Surv., Mon. 38, 1899.
⁷ Calvin, Samuel, *Iowan Drift*: Bull., Geol. Soc. Amer., 10, 107-120, 1899.

of interest to note that in this paper Calvin stated that he believed that the Kansan drift was certainly fifteen and possibly fifty times as old as the Iowan, and that judging by the changes that had been wrought in the surface of the Illinoian before the loess was laid down on it, this sheet of till was at least five or six times as old as the Iowan.

For some years it was thought that the main loess deposit of the Iowan area in northeastern Iowa and of the Illinoian area of southeastern Iowa was of the same age as the Iowan drift and was aqueous in origin. It was called Iowan loess. But detailed studies soon showed that the main loess deposits were eolian and not aqueous in origin.⁸ The loess continued to be considered genetically related to the Iowan drift. In recent years it has been interpreted to represent "the early part of the Peorian stage of deglaciation."⁹

The Iowan Drift Questioned by Leverett.

About the year 1907 the reality of the Iowan drift of northeastern Iowa began to be questioned. Leverett¹⁰ in a paper in which he discussed the application of weathering and erosion to the correlation of drifts questioned the existence of the Iowan drift. He expressed the view that the topography of the Iowan area in northeastern Iowa was of the erosional type such as characterizes the Kansan drift but that in northeastern Iowa tabular divides are lacking and none of the drift is fresh. He believed that filling of the valleys by slope wash in the Iowan area accounted for the difference in topography of this area and that of the Kansan of southern Iowa.

Leverett's skepticism of the Iowan followed field study in the Iowan area, one of the objects of which study was to determine whether or not the Iowan drift was in reality Illinoian drift from the Keewatin field. He concluded that the surface material was not different from the weathered Kansan drift and that if any post-Kansan drift was present it was probably of Illinoian age. His views were influenced possibly by his

⁸ Shimek, Bohumil, Papers on the loess, Loess and the Lansing man, Loess and the Iowan drift: Univ. of Iowa, Lab. of Nat. Hist., 5, 298-381, 1904.

⁹ Alden, W. C., and Leighton, M. M., The Iowan Drift—a Review of the Evidences of the Iowan Stage of Glaciation: Iowa Geol. Surv. 26, 158.

¹⁰ Leverett, Frank, Weathering and Erosion as Time Measures: this journal, 27, 349-368, 1909.

studies of the glacial deposits of Europe. There, only four distinct drift sheets had been established by students of the Pleistocene, and in comparing with the American section it was only natural that an earnest effort should be made to analyze and interpret the American deposits in terms of four rather than five glacial drifts. His views are given in a paper¹¹ in which the North American and European glacial deposits are compared. In referring to the Iowan drift, he used the expression "so-called Iowan of the Keewatin field (Illinoian)."

Calvin's Defense of the Iowan.

Calvin¹² came to the defense of the Iowan. He and his associates on the Iowa Geological Survey believed that the evidence favored strongly the argument that the Iowan drift was distinct from both the Kansan drift and the Illinoian drift. They had for many years mapped the Iowan drift in many counties and were agreed that this drift was the drift which McGee described as his Upper Till. In that part of Calvin's paper which deals with the evidence of the reality of the Iowan drift and its geological relations, he expressed surprise at the attitude taken by Leverett with regard to the Iowan, and presented strong evidence in support of each of the following affirmations: (1) The Iowan drift is. (2) The Iowan drift is young as compared with the Kansan. (3) The Iowan drift is not a phase of the Kansan. (4) The Iowan drift has very intimate relations to certain bodies of loess. (5) The Iowan drift is not related to the Illinoian.

In regard to the lack of relationship of the Iowan to the Illinoian, Calvin stated:

"It is scarcely necessary to discuss the suggestion that the Iowan may be correlated with the Illinoian. Parenthetically it may be said that if the Iowan and the Illinoian represent the same stage of glaciation, the name Illinoian becomes a synonym for Iowan, and we shall be reduced to the painful necessity of referring to one of our most beloved drift sheets as the 'so-called Illinoian.' But no such calamity awaits the Illinoian. The Iowan is much the younger of the two. As indicated by the structural and genetic relations above noted, the Iowan—a little later probably than its maximum stage—is practically contemporaneous with the loess; and as the Berlin paper, with noteworthy lucidity, con-

¹¹ Leverett, Frank, Comparison of North American and European Glacial Deposits, *Zeits. für Gletscherkunde*, B. 4, 241-295, 321-342, 1910.

¹² Calvin, Samuel, The Iowan Drift: *Jour. Geol.*, 19, 577-602, 1911.

rectly states on p. 299; 'the Sangamon interval separates the loess from the Illinoian stage of glaciation so widely that there would seem to be no relation between loess deposition and Illinoian outwash.' The same long interval, the same wide separation, exists between the Iowan and the Illinoian stages of glaciation. The two drifts are not related in time in any other way."

Alden and Leighton's Review of the Evidences of the Iowan Stage.

After the death of Calvin in 1911 it seemed highly desirable to have a review of the evidence bearing upon the Iowan problem, and hence with the hope that a satisfactory solution to the question in controversy might be reached, the writer, Calvin's successor as State Geologist of Iowa, asked the United States Geological Survey to undertake the investigation in co-operation with the Iowa Geological Survey. It was agreed that W. C. Alden of the Federal Survey should be assigned to this work and that he should be assisted by M. M. Leighton of the Iowa Survey. Field work was carried forward during two seasons and in the office careful study was given to published and unpublished material related to the Iowan problem. The results of the investigations of Alden and Leighton were published in Volume XXVI of the reports of the Iowa Geological Survey.¹³ In the Introduction to this report, page 56, it is stated:

"It is a pleasure to report that the conclusion has been reached that there is what seems to the writers to be good evidence of the presence of a post-Kansan drift sheet in northeastern Iowa and that this drift appears to be older than the Wisconsin and younger than the Illinoian drift. The writers are, therefore, in the main in agreement with the late State Geologist, Dr. Samuel Calvin, in regard to the Iowan drift. There is, therefore, warrant for continued use of Iowan drift and Iowan stage of glaciation as major subdivisions of the Pleistocene classification."

The chief lines of evidence which caused Alden and Leighton to reach the conclusion that the Iowan drift is a reality and is distinct from other drifts were the following:

(1) *The topographic character of the Iowan area.* It is pointed out that the topography of the Iowan area is not that

¹³ Alden, W. C., and Leighton, Morris M., The Iowan Drift, A Review of the Evidences of the Iowan Stage of Glaciation: Iowa Geol. Surv. 26, 49-212, 1917.

of a normally eroded surface like the typical Kansan surface of southern Iowa, but rather it is a drift mantled, erosional topography. There are surface irregularities which are the result of glacial deposition rather than differential erosion. Distinct moraines associated with which are kames of fresh gravels are cited. Examples are given of valleys which are cut deep in the Kansan area and which flatten out where they head in the Iowan area where cutting is in drift and not in bed rock. The Iowan area as a whole lacks the accordance of upland levels of the tabular divides so characteristic of the erosional Kansan area of southern Iowa. The lack of accordance in the Iowan area seems to be due to unequal mantling by glacial drift, which is confirmed by the presence in many places of relatively fresh drift on gumbotil which can be proven to be Kansan gumbotil.

(2) *The character of the uppermost till of the Iowan area.* It is shown that the degree and depth of oxidation, depth of leaching and other evidences of weathering indicate that the drift of the Iowan area is much younger than the drift of the Kansan area.

(3) *The gumbotil.*¹⁴ Gumbotil is widespread at the top of the Kansan till in southern Iowa where tabular divides are preserved.¹⁵ The topographic position of the Kansan gumbotil is such that it has been possible to trace remnants of it into the Iowan area. And wherever the Kansan gumbotil has been found in the Iowan area it is overlain by a thin mantle of drift which is the Iowan drift.

(4) *The loess.* After having made detailed studies of the loess in the Iowan, Kansan, and Illinoian areas, Alden and Leighton reached the following general conclusions: (a) that the deposition of the uppermost till of the Iowan drift area occurred but a short time prior to the accumulation of the main sheet of loess which borders and overlaps it; (b) that the Illinoian till was deposited at a time considerably before this epoch of loess deposition; and (c) that the Kansan drift was deposited considerably earlier than the Illinoian till and much earlier than the loess was formed, or in other words, this line of evidence also supports the view that the Iowan stage of glaciation was distinct from, and later than either the Kansan or Illinoian stages of glaciation.

¹⁴Kay, Geo. F. Gumbotil, a new term in Pleistocene geology: Science, N. S., 44, 637-638, 1916.

¹⁵Kay, Geo. F., Some Features of the Kansan Drift in southern Iowa. Bull. Geol. Soc. Amer. 27, 115-117, 1916.

In connection with the discussion of the age of the Iowan drift, Alden and Leighton presented evidence for their belief that the Iowan drift is a distinct drift from the Illinoian drift. They stated:

"From these various observations it is evident that the Illinoian drift has been modified much more by weathering and erosion than has the Iowan. It also appears that most of the modification occurred prior to the formation of the main deposit of loess. It appears clear therefore that the Iowan drift is entirely distinct from and considerably younger than the Illinoian drift."

Study of Recent Exposures within the Iowan Area.

The last field work done by Alden and Leighton within the Iowan area was in 1915. During a part of each field season since that time the writer has seen all the important exposures which have been made in that area in connection with Iowa's extensive road grading program. Detailed studies of the many widely distributed cuts have strengthened the interpretations of Alden and Leighton. Exposures showing Iowan till underlain by Kansan gumbotil have been found in nearly every county of the Iowan area and in some counties many outcrops of this character are known. The locations of known exposures of Kansan gumbotil overlain by Iowan till are shown in Fig. 4. This is the most impressive evidence within the area in support of the existence of a post-Kansan drift, the Iowan.

Perhaps the best exposure showing the Kansan till and the Iowan till separated by Kansan gumbotil is near the middle of the north line of the northeast $\frac{1}{4}$ of section 16, Windsor township, Fayette county. The elevation of the gumbotil here is about 1,200 feet, and it is seen at the same elevation in several cuts along the road to the east within the few miles to West Union. The section made in the main cut (Fig. 2) is as follows:

- | | |
|--|-----------------|
| 5. Loess (Peorian), buff, mealy; unleached; some concretions, fossil shells found | 2 feet |
| 4. Till (Iowan), dark buff on a dry surface, yellowish brown to brown when damp; cuts readily with the hoe; sandy; few if any concretions; all unleached .. | 7 feet |
| 3. Loess (Loveland), gray with considerable chocolate colored stain; <i>leached</i> ; laminated; puttylike when wet; free from grit and no pebbles found in it | 2 feet 6 inches |
| Gumbotil (Kansan), dark gray on a dry surface; leached; no concretions seen; very few pebbles of any | |

- kind, and those present are silicious; upper one foot and a half has much carbonaceous matter which shows as a distinct soil band through the cut 5 feet 6 inches
- i. Till (Kansan); oxidized and leached, grades into the gumbotil; pebbles abundant; exposed for 4 feet 6 inches

It will be observed that in the above section beneath the Iowan till there is more than 2 feet of Loveland loess. Reference will be made later to the significance of Loveland loess.



Fig. 1. Road cut near the middle of the north line of the northeast $\frac{1}{4}$, Section 16, Windsor township, Fayette county, showing Kansan gumbotil overlain by Loveland loess, overlain by Iowan till, overlain by Peorian loess.

Study of the road cuts has emphasized the wide distribution of thin loess overlying a distinct pebble band at the surface of the Iowan till. Thick loess which is apparently genetically related to the Iowan till is uniformly present at the borders of the Iowan. This loess thins with distance from the Iowan and furthermore the constituent particles of the loess are largest at the borders of the Iowan and smaller and smaller as distance increases from the border. Some deposits of loess are along river valleys draining from the Iowan drift area.

A most impressive fact is the relation of the depth of leaching of the Iowan till to the thickness of the overlying loess. Where loess is absent the till is leached to a depth of three or

four feet. Where loess overlies the till and is sufficiently thick to be unleached in its lower part the Iowan till is unleached to its surface. Where the loess is thin and leached, the till below is also leached, the combined leaching of the loess and till not exceeding five or six feet. This relationship holds consistently. It is the best evidence in support of the view that the loess was laid down on the Iowan till before the till had been exposed for a sufficient time to be leached. This kind of evidence was

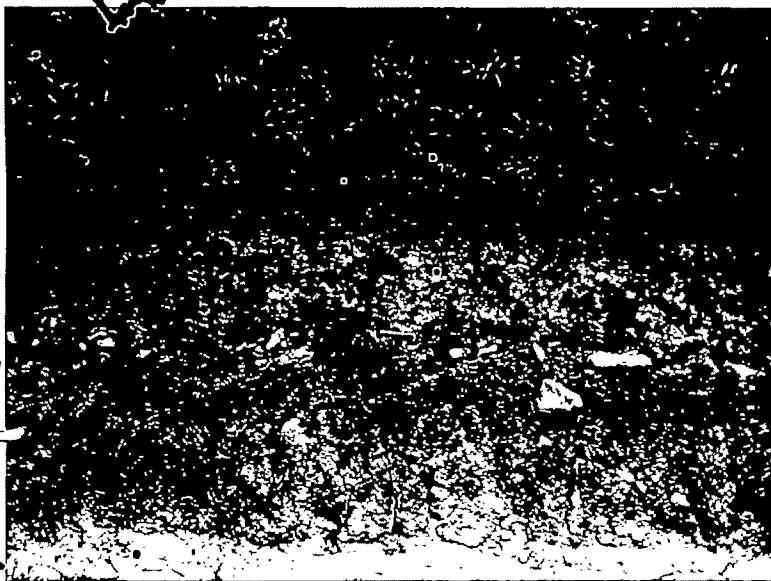


Fig. 2. Road cut between sections 1 and 2, Fremont township, Cedar county, showing thin pebble band with Iowan till below and Peorian loess above.

presented most effectively by Alden and Leighton in their report on the Iowan drift area.

Although the pebble band is on the Iowan till and beneath the loess it is thought that no great length of time was involved in its formation. The writer agrees with the view expressed by Alden and Leighton that the pebble band is probably the residue from wash and wind erosion of the upper part of the till.

One of the best exposures in the whole Iowan area showing the line of pebbles with Iowan till below and loess above was observed in the middle of the line between sections 1 and

2 Fremont township, Cedar county (Fig. 2). The section is as follows:

1. Loess (Peorian), brownish, leached 4 feet
2. Pebble band, a thin row of pebbles.
3. Till (Iowan), grayish-yellow to yellow color, sandy, contains sand pockets, jointed, not strongly oxidized, no ferretto; upper 1 foot 3 inches leached, lower part unleached 5 feet

Some of the fragments of rock in the pebble band show wind polish (Fig. 3).



Fig. 3. One of the rock fragments of pebble band underlain by Iowan till and overlain by Peorian loess.

Another most interesting fact brought out by recent studies in the Iowan area of northeastern Iowa is the relative depths of leaching of upland Iowan gravels and upland Kansan gravels. Whereas in places the Kansan upland gravels are leached to depths of more than twenty feet, the Iowan upland gravels, where they overlie Kansan gumbotil (and hence there can be no doubt regarding their age), are leached to a depth of less than five feet. Moreover, the depth of leaching of

upland Iowan gravels, as of Iowan till, is dependent upon the depth of leaching of the overlying loess.

Field Conference in Northeastern Iowa in 1925.

On July 20, 1923, Frank Leverett in a letter written to T. C. Chamberlin, W. C. Alden, M. M. Leighton, and the writer, with regard to an appropriate name to be given to the loess overlying the Iowan and Illinoian tills, stated: "I still regard the occurrence of a drift such as outlined by Calvin (i.e., Iowan drift) as unsettled." Since Mr. Leverett had not been in northeastern Iowa for several years prior to the time this statement was made, and hence had not seen the strong evidence in favor of the Iowan drift which had been made available for study in the many road cuts and other exposures which were made in connection with new road grading within the Iowan area, the writer invited Mr. Leverett to accompany him into northeastern Iowa in the summer of 1925. He accepted the invitation and together we examined some of the most significant exposures within the Iowan area. Paul MacClintock of the University of Chicago and my assistant, E. T. Apfel, accompanied us. Agreement of interpretation was reached on all important matters with the exception of the significance of the pebble band on the Iowan till. Mr. Leverett contended that the pebble band was the result chiefly of erosion by running water and that much time had been involved in its formation. He favored the view that the till on which the pebble band had been formed was the result of an ice sheet from the Keewatin field and equivalent in age to a late phase of the Illinoian drift. He was of the opinion that the time between the retreat of the ice from the Iowan area and the deposition of the overlying loess was comparable to the time between the retreat of the Illinoian ice from southeastern Iowa and the deposition of the loess overlying the Illinoian drift, which loess is of the same age as that overlying the Iowan drift. He would make the Iowan drift the product of a late phase of the Illinoian stage of glaciation and would give the name Sangamon to the interval between the Iowan drift and the overlying loess as well as to the interval between the Illinoian drift and the loess which overlies it.

This interpretation of Leverett's could not be accepted by the writer. The evidence which had been presented by Calvin and later by Alden and Leighton was emphasized in support

of the view that the Iowan drift is young in comparison with the Illinoian and hence should be retained as a separate glacial

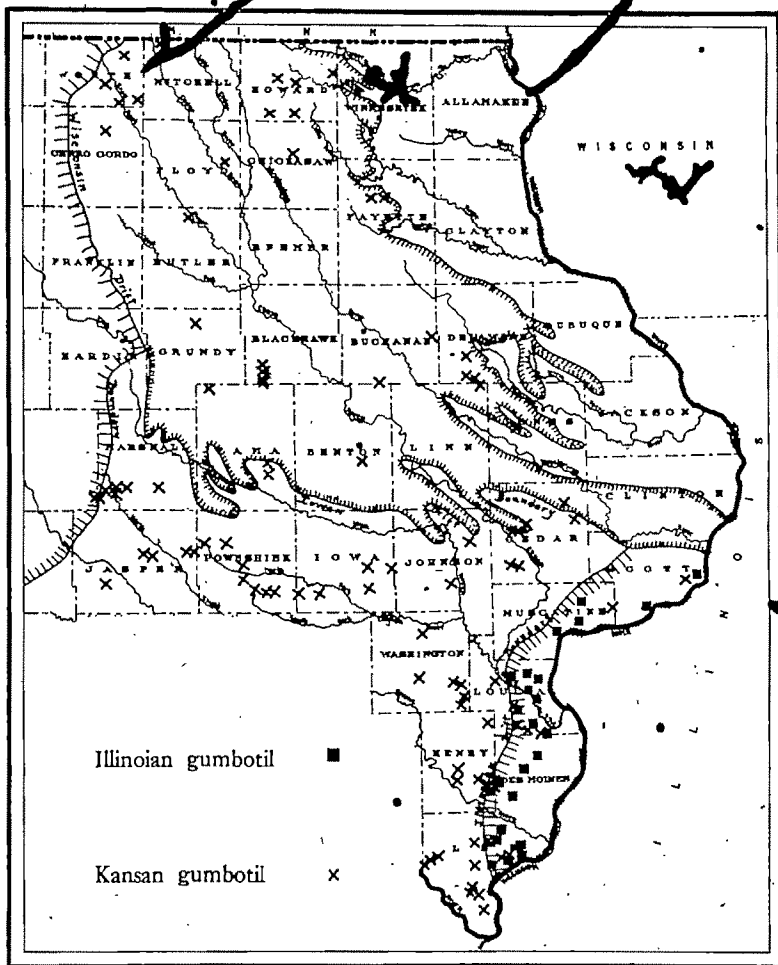


Fig. 4. Map showing locations of known exposures of Kansan gumbotil underlying Iowan till, in the Iowan drift area of northeastern Iowa and underlying Illinoian till in the Illinoian drift area of southeastern Iowa; also the locations of some of the known exposures of Illinoian gumbotil on the Illinoian till.

stage in our classification. It was pointed out that the strongest argument in support of the Iowan drift being younger than the Illinoian drift is the presence over wide areas in south-

eastern Iowa and Illinois of from three to four feet of Illinoian gumbotil on the Illinoian till and beneath the Peorian loess, whereas in the Iowa area the Iowan till is leached only to a depth of a few feet and is so young comparatively that gumbotil has not yet been developed anywhere on this till, not even where the topographic position of the Iowan till is very similar to the topographic position of the Illinoian till, e.g., on the uplands. Fig. 4 shows the locations of known exposures of Kansan gumbotil underlying Iowan till in the Iowan drift area and the Illinoian till in the Illinoian drift area; also the locations of some of the known exposures of the Illinoian gumbotil on the Illinoian till; no gumbotil has been developed on Iowan till.

Suggested Correlation of Iowan with Illinoian Till.

All persons who have done field work in northeastern Iowa in recent years are now agreed that there is in that area a post-Kansan till. Moreover, it has been shown in the past few years that a till of the same age is present in northwestern Iowa west of the border of the Wisconsin till. Members of the Iowa Geological Survey are convinced that the tills of both areas are Iowan and much younger than the Illinoian. Mr. Leverett, however, although he is of the opinion that the tills of the two areas are of the same age, suggests that they should be correlated with the Illinoian till. This viewpoint was expressed in our field conference and later in the paper read before the American Philosophical Society in Philadelphia.¹⁶

This is a most admirably written paper in which the author gives a clear and concise statement of his views of the Pleistocene based upon his many years of detailed study. His interpretations are presented in such a convincing manner that they will carry conviction with all persons who have not been actively engaged in recent years in a critical field study of glacial and interglacial deposits in all their relationships. His discussions of the oldest drift, the Jerseyan or Nebraskan, of the second drift, the Kansan, and of the youngest drift, the Wisconsin, are likely to be accepted without adverse criticism. But the part of Mr. Leverett's paper which is open to attack is that part which deals with "the Iowan drift of northeastern Iowa and its probable correlatives." Before presenting his

¹⁶ Leverett, Frank, The Pleistocene Glacial Stages: Were There More Than Four? Proc. Am. Phil. Soc., 65, No. 2, 1926.

reasons for favoring the correlation of the Iowan drift with the Illinoian drift he states: "If it is granted that the Iowan drift stands for a glacial stage between the Illinoian and Wisconsin stages there were five glacial stages in America." The vital question then is, is the evidence which is favorable to the correlation of the Iowan with the Illinoian of sufficient weight to offset the strong evidence in support of the Iowan and Illinoian being considered as independent stages?

Mr. Leverett in his paper calls to the reader's attention the fact that for some time after the Iowan drift was differentiated from the Kansan drift in northeastern Iowa the opinion prevailed that the widespread loess of the area was aqueous in origin and was of the same age as the Iowan. However, in this connection it should not be forgotten that as early as 1904 the view that was accepted quite generally in Iowa was that the loess is not aqueous but is eolian in origin. From that time to the present it has been the judgment of all persons connected with the Iowa Geological Survey, and others, that the loess is not Iowan in age but was deposited a comparatively short time after the retreat of the Iowan ice. This was the view of Calvin in the later years of his life, and the view which was advanced by Alden and Leighton in their report on the Iowan drift in the 1915 Annual Report of the Iowa Geological Survey.

It is to the interpretation that the loess overlying the Iowan till was deposited but a short time after the retreat of the Iowan ice sheet that Leverett takes exception. It is here that he finds his chief basis for suggesting the correlation of the Iowan till with the Illinoian till. He emphasizes the significance of the pebble band which separates the Iowan till from the overlying loess. The pebble band which was seen by Leverett, MacClintock, Apfel and the writer in the summer of 1925 is described in his paper in some detail. Here he states the judgments which he expressed in the field conference to which reference has already been made. He believes that the pebble band is the result of slope wash rather than of wind action. He thinks that a great length of time was necessary for the development of this pebble band, and hence the loess overlying the pebble band must be very much younger than the Iowan till upon which the pebble band lies.

Leverett states in his paper that the Iowan drift "lies wholly within the limits of what has been termed the Keewatin field of glaciation." And then after having presented some facts

with regard to the growth of ice sheets, particularly with reference to the Wisconsin, he applies the same principles to the method of growth of the Illinoian. He states "It seems but natural that westward growth such as we know affected the Wisconsin ice sheet should also have occurred in the Illinoian stage and given the ice movement that brought in the Iowan drift." Here we have his theoretical grounds for thinking that the Iowan drift should be correlated with the Illinoian.

Mr. Leverett gives but brief consideration to the evidence that has been presented by Calvin, Alden and Leighton, the writer, and others in support of the interpretation that the Iowan and Illinoian glacial stages were widely separated in age. He attempts briefly to explain the lack of gumbotil on the Iowan and in places on the Kansan. The absence of gumbotil on the Iowan could be explained, he believes, by the lack of summit flats. In this connection it should be stated that some parts of the Iowan area have the same topographic position and character as the upland flats of the Illinoian area upon which the gumbotil is found. His reference to lack of gumbotil on the Kansan in northwestern Iowa is without significance since he failed to recognize that the writer and others have presented field evidence to warrant the interpretation that gumbotil was developed on the Kansan till in that area, and that in connection with the development of the present topography in that area the gumbotil was eroded, leaving the oxidized and unleached Kansan till with much secondary calcium carbonate at the surface.¹⁷

In closing his discussion of the Iowan in relation to the Illinoian Leverett states:

"In view of all the features of the Iowan drift, taken in connection with the fact that it stands as the third drift of the western district, as the Illinoian does of the eastern, and that each district has but four drifts, the writer raises the question whether there really were more than four Pleistocene glacial stages in North America, or whether the Iowan drift should be regarded as a late phase of the third glacial stage. Features of the Iowan drift and its relation to the loess seem to demand further critical field study."

¹⁷ Kay, G. F., Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Surv., 26, 218-219, 1917.

Carman, J. E., The Pleistocene Geology of Northwestern Iowa: Iowa Geol. Surv., 26, 332-334, 1917.

It must be kept clearly in mind that Leverett now is suggesting four glacial stages instead of five, not because he questions the existence of the Iowan drift as he did until recently, but for the reason that he believes the Iowan drift may be a late phase of the Illinoian and hence should be correlated with that drift sheet. The task therefore is no longer that of proving whether or not there is an Iowan drift, but of showing even more definitely than has been done thus far the relations of the Iowan drift to the Illinoian drift. Until this has been accomplished there will be confusion in the minds of all persons with regard to a proper classification of the North American glacial deposits, and during this time some persons will reach the judgment quite naturally that four glacial stages should be included in the North American classification and that these four can be correlated with four glacial stages in Europe. This unfortunately has been done already.¹⁸ In recent years H. F. Osborn and Chester Reeds have published several papers in which only four glacial stages are included in their classification of North American glacial deposits.

SIGNIFICANCE OF LOVELAND LOESS.

The writer as a result of recent field studies in the Iowan, Illinoian and other areas of Iowa is now able to present evidence which when combined with evidence already presented would seem to prove conclusively that the Iowan glacial stage is much younger than the Illinoian glacial stage.

The additional evidence is the occurrence of a wide-spread weathered loess, the Loveland loess, which is younger than the Illinoian drift and older than the Iowan drift. In a brief paper now in press the writer¹⁹ states that the relationships of the Loveland loess have been worked out sufficiently definitely by stratigraphic methods in the Iowan and Illinoian drift areas to justify the following conclusion: "The Loveland loess was deposited after the development over wide areas, chiefly by chemical weathering, of a gumbotil more than three feet thick on the Illinoian till. Furthermore, there was sufficient time after the Loveland loess was laid down for this loess to be leached to a depth of several feet before the coming of the Iowan ice sheet."

¹⁸ Hay, O. P., Pleistocene Man in Europe and America: Reprinted from the New York Herald-Tribune of July 1, 1928, with slight changes.

¹⁹ Kay, G. F., Loveland Loess: Post-Illinoian, Pre-Iowan in Age: Science, in press, Nov., 1928.

One of the best exposures showing the Loveland loess beneath the Iowan till of northeastern Iowa is near the middle of the north line of the northeast $\frac{1}{4}$ of section 16, Windsor township, Fayette county. This section was referred to previously in this paper in a discussion of the Iowan till in relation to Kansan gumbotil.



Fig. 5. Road cut near the middle of the north line of the northeast $\frac{1}{4}$, Section 16, Windsor township, Fayette county, showing Loveland loess overlying Kansan gumbotil and underlying Iowan till.

A good section showing the Loveland loess overlying Illinoian gumbotil is in a road cut west of Davenport on Primary road 22. It is less than one mile west of the junction of Primary roads 61 and 22. It is in the south part of section 31, Davenport township, Scott county. The section is as follows:

- | | |
|--|-----------------|
| 5. Loess (Peorian), buff color, lower part gray and unleached | 8 feet |
| 4. Loess (Loveland), brown color, leached, some secondary calcium carbonate along joints and root canals | 1 foot 6 inches |
| 3. Gumbotil (Illinoian) | 3 feet |
| 2. Till (Illinoian), oxidized and leached | 3 feet |
| 1. Till, oxidized and unleached to base of cut. | |

Norton in his report on the Geology of Scott County referred to the deposits in the vicinity of Davenport which are now

called Loveland loess as "red loam." Reference was made to these deposits by Leverett also in his monograph on the Illinois Glacial Lobe. In places a soil zone separates the Love-

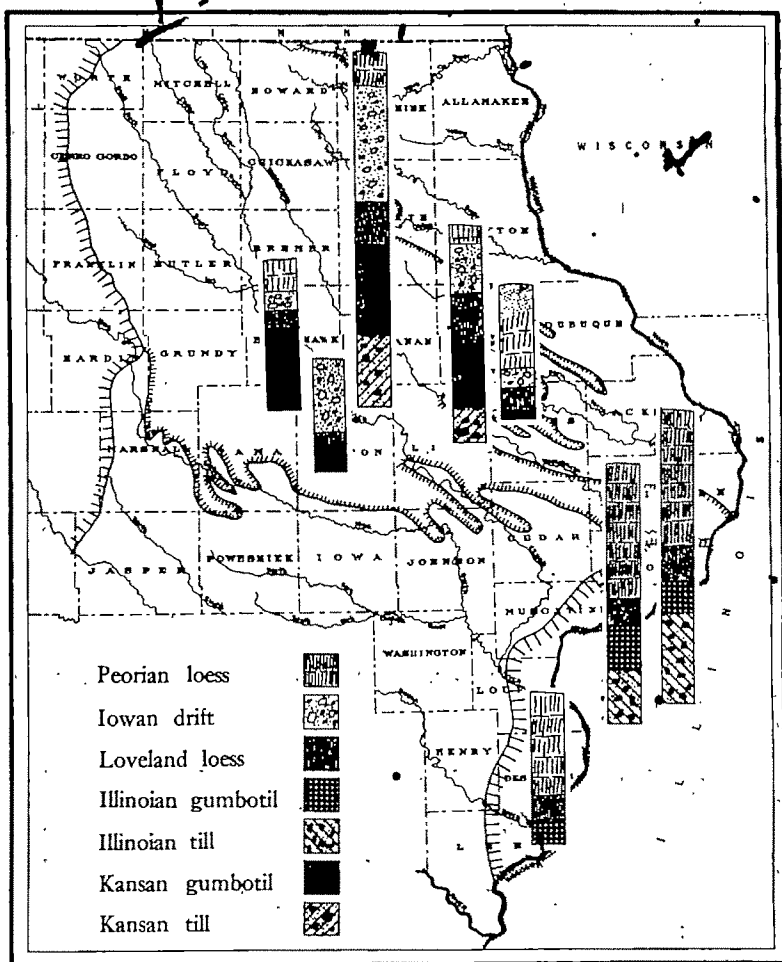


Fig. 6. Shows graphically the relation of the Loveland loess to the Iowan and Illinoian tills in northeastern and southeastern Iowa, respectively.

land loess from the overlying material. In places the Illinoian gumbotil was eroded before the Loveland loess was deposited.

Fig. 6 represents graphically the relation of the Loveland loess to the Iowan and Illinoian tills in northeastern and southeastern Iowa, respectively.

CONCLUDING STATEMENTS.

McGee was the first geologist to describe the till of north-eastern Iowa which for more than thirty years has been called Iowan till. Calvin and his associates on the Iowa Geological Survey studied in detail and mapped the Iowan till in many counties in McGee's type area. Later, when the existence of the Iowan drift was questioned by Leverett, Alden of the United States Geological Survey and Leighton of the Iowa Geological Survey restudied in coöperation the evidences of the Iowan drift, reaching the judgment that there was warrant for continued use of Iowan drift and Iowan stage of glaciation as major sub-divisions of the Pleistocene classification. Still for several years after this time Leverett continued in the belief that the Iowan problem had not been settled. But now he too recognizes that there is Iowan drift.

It is gratifying indeed that a drift about which for many years there was so much controversy as to its existence now has the approval of all geologists who in recent years have studied the field evidence critically. But now there has arisen the question as to whether or not the Iowan drift is distinct in age from the Illinoian drift. Leverett, chiefly on the basis of his interpretation of the significance of the pebble band or thin pebble concentrate on the Iowan till, and on theoretical grounds, suggests the correlation of the Iowan drift with the Illinoian drift. The chief arguments against his interpretation are found in the views of Calvin, Alden and Leighton, and the writer, as expressed in this paper. The strongest of several arguments in favor of a long time interval between the Illinoian and Iowan glacial stages are the occurrence of a gumbotil on the Illinoian in contrast to no gumbotil on the Iowan, and the leached Loveland loess which is post-Illinoian gumbotil, pre-Iowan in age.

The relative ages of the Iowan and Illinoian glacial stages would seem to have been established, and hence five glacial stages and four interglacial stages must continue to be given a place in the classification of the North American glacial deposits. The oldest of these stages is the Nebraskan or Jerseyan, at the surface of the till of which there was developed during the Aftonian interglacial stage a gumbotil with an average thickness in Iowa of more than eight feet. The second glacial stage is the Kansan, on the surface of the till of which there was developed during the second interglacial

stage, the Yarmouth, a gumbotil with a maximum thickness of about fifteen feet and with an average thickness of more than eleven feet. The third glacial stage is the Illinoian. During the third interglacial stage, the Sangamon, a gumbotil was developed widely on the Illinoian till to a depth of more than three feet, and later a loess, the Loveland loess, was deposited over the Illinoian gumbotil and older Pleistocene deposits. This loess in places was leached and a soil formed on its surface before the close of Sangamon time. The fourth glacial stage is the Iowan, now well determined in northeastern and northwestern Iowa. Its characters are just as distinctive as are the characters of other glacial stages. The fourth interglacial stage is the Peorian. During this stage the Iowan till was leached to an average depth of less than five feet. Apparently the widespread Peorian loess was laid down by wind action very soon after the retreat of the Iowan ice, and hence is early Peorian in age. The evidence indicates that the Peorian interglacial stage was by far the shortest of the interglacial stages. The youngest glacial stage is the Wisconsin. The writer wishes to remark that if there be any merit in having four glacial stages rather than five then the two stages which are related the most closely in age are the Iowan and Wisconsin. Peorian loess, which is the most distinctive interglacial material separating the drifts of these two stages, is in part related closely both genetically and in age to the Iowan and, moreover, this loess was not changed greatly by weathering before the coming of the Wisconsin ice sheet. •However, at present it seems best to continue to treat the Iowan glacial stage as a stage independent from the Wisconsin. And it has been shown that there is no adequate basis for correlating the Iowan stage with the Illinoian stage.

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missing. While the structure of the posterior portion of the column is obscure, counts of neural and haemal arches show that the number of caudals with double centra is about 18. This gives a total of 52, as compared with close to 80 in *Amia calva*. A series of posterior dorsals have an average length of 7 mm., and more anterior single elements give close to the same measurement. A posterior dorsal seen in end view has a depth of 10 mm. and a breadth of 12.5 mm. Less perfectly preserved anterior elements are of about the same size. In all cases observed the ventral margins are well-rounded, and without conspicuous angulation of the sides. Several successive caudals from the middle of the series give an average length for the double element of 9 mm. and a depth of 10.5 mm. The width and shape are not obtainable.

The neural spines average about 50 mm. in length, a figure somewhat proportionately greater than in *Amia*. The ribs are not well preserved. The haemal spines average 60 mm. in length, being about half again as long as in an *Amia* of similar size.

The skull bones are well preserved, only the parietal, the post-temporal, the suborbitals, and the small bones in the nasal region being badly broken or deranged. For this reason the accompanying reconstruction of the skull is believed to represent a close approximation to the original proportions.

The most distinctive features of the skull of our specimen when compared with the skull of *Amia cavia* is its depth and shortness. The length of the skull together with the opercular apparatus is 13.5 centimeters, while that of *Amia* is 14.8 centimeters; and the depth of the skull to the base of the quadrate is 7.4 centimeters as against 6.3 centimeters in *Amia*.

These proportions of the skull result from a corresponding fore-and-aft shortening of the larger skull elements. Thus the opercular and the combined postorbitals are higher than they are broad, whereas in *Amia* the converse is true. Similar shortening of the dentary, angular, and maxillary bones gives our specimen a mouth that is distinctly smaller than that of *Amia*. Several of the other larger elements of the skull, especially the subopercular, the postfrontal, and the lachrymal, reveal a corresponding difference in proportion when compared to their equivalents in *Amia*. The following table gives the measurements of those bones which give to the skull its distinctively shortened and deepened aspect, the measurements for the corresponding elements in *Amia* being added for the

All of the bones of the skull are so heavy as to be platelike in character, which fact in large measure explains their excellent preservation in this specimen. Their surfaces are pitted, and on the frontal the pits are arranged in radial lines. On the opercular are faint grooves that radiate downward and backward from the anterior-dorsal corner.

The thickness of certain of the elements is emphasized by the shaping of their outer surfaces into grooves, ridges, or knobs. As is shown on the sketch, such forms are especially distinctive on the postorbitals, the preopercular, the interopercular, the lachrymal, and the post-temporal. Around the posterior margin of the orbit the postorbitals (which in this specimen are not fused) are deeply cut away, and back of the resulting crescentic depressions the postorbitals are thickened into prominent ridges. The postorbitals are thus the most massive elements of the skull. The lachrymal and the interopercular appear centrally depressed as a result of the thickening of their margins.

Systematic position. This form is obviously generically distinct from *Amia*.¹ Some five other generic names are available for Tertiary amiids, *Protamia* and *Hypamia* of Leidy² and *Pappichthys* of Cope,³ used for Bridger forms; and *Cyclurus*⁴ and *Notaeus*⁵ of Agassiz, from the Tertiary of Europe. Agassiz's types are *C. valenciennesi* of the Aquitanian (Lower Miocene) and *N. laticaudatus* of the Sannoisian (Upper Eocene) of France. In both cases the body outline is known; they are small forms with proportions similar to those of *Amia*. Later writers have generally, and seemingly properly, included them in the living genus.

Comparison with the Bridger genera is difficult on account of the fragmentary nature of the latter material. *P. uintaensis*, the type of Leidy's *Protamia*, is known from only a few vertebrae and basioccipital.⁶ This is a form more than three times the size of ours, a dorsal vertebra measuring 33 mm. in height and 42 mm. in breadth. The centra are proportionately much shorter, the length being contained in the breadth about three times, whereas dorsals of our form have a length

¹ *Amia*, of some taxonomists. See Jordan and Seale, Bull. U. S. Bur. Fisheries, 25, 237, 1905.

² Proc. Acad. Nat. Sci. Phila., 97-99, 1873.

³ Sixth Ann. Rept., U. S. Geol. Surv. Terr., 634, 1872 (1873).

⁴ Poissons Fossiles, 5, pt. 1, 12, 1844; pt. 2, 44, pl. liii.

⁵ *Ibid.*, pt. 1, 65; pt. 2, 127, pl. xlii.

⁶ Sixth Ann. Rept., U. S. Geol. Surv. Terr., 185-187, pl. xxxii, 1872 (1873).

somewhat more than half the width. *Pappichthys plicatus* is the type of Cope's genus. He describes isolated skull elements, as well as vertebrae, of a form of large size.⁷ Cope would discard Leidy's genera because they were founded on vertebrae alone and were not given a diagnosis. However, the only diagnostic character given by Cope other than the character of the vertebrae is that the bones on the borders of the mouth bear but one set of teeth. Newton⁸ has pointed out that this is true of *Amia* as well, the supplementary rows of teeth being borne on internal elements. The shortness of the vertebrae is a good diagnostic feature, Cope's specimens showing the length to be about one-third the breadth, as in *Protamia*. Since this is the only distinguishing character of Cope's genus, and this point is prominently mentioned by Leidy in his description of the type form, *Protamia* may well stand, and *Pappichthys*, as far as our knowledge goes, is a synonym.

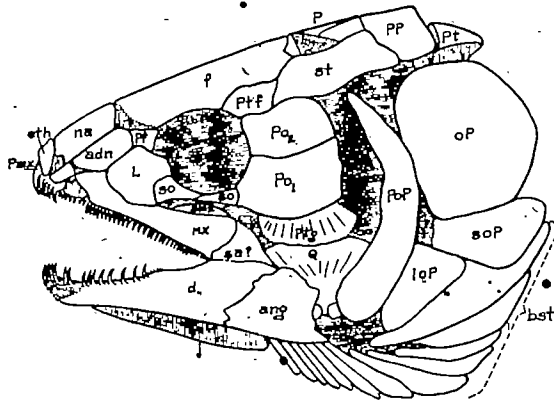


Fig. 3. Restoration of skull of *Paramiatus gurleyi* $\times \frac{1}{2}$. Abbreviations, same as in Fig. 2. Stippled areas in figure represent portions missing in specimen.

Hypamia elegans, the type of Leidy's second genus, is founded on a single centrum,⁹ which is of about the size of the posterior dorsals of our specimen, and lacks the thinness of *Protamia*. However, this same type of centrum is found in living amiids, and is in general not distinctive. The only feature that Leidy points out as characteristic is that ventrally

⁷ Rept. U. S. Geol. Surv. Terr., III, 59, pls. iii, iv, 1884 (1885).

⁸ Quart. Jour. Geol. Soc. London, 55, 1-2, 1899.

⁹ Op. cit., 188, pl. xxxii.

the two edges converge to a median prominence. This may be characteristic of only a point in the column; it is not true of any centrum in our specimen which can be seen in end view, and while future discovery may show that this belongs to a deep-bodied form, it is equally probable that this is a true *Amia*.

Thus our specimen cannot be placed in any one of the present amiid genera. It is quite possible that our form may have persisted into the overlying Bridger beds, from which some eleven species have been described. But possibly similar forms in that horizon are so imperfectly known that it appears better to designate this specimen as *Paramiatus gurleyi*, gen. et spec. nov., characterized by the shortness and depth of the body and skull, the thickness of dermal bones and the more anterior position of pelvic fins.

Relationships. We have sought without success to find certain evidence of related deep-bodied forms among other Tertiary amiids.

In the early Tertiary a considerable proportion of described species belonging to this family are of the *Protamia* (*Pappichthys*) type. The oldest known form of this sort is *P. robusta* Priem¹⁰ of the Thanetian of Cernay (Cope¹¹ states that amiids are found in the Puerco and Wind River, but he has given us no descriptions). This form is also reported from the Eocene of Russia by Stoyanow.¹² *P. morini* Priem,¹³ from the Sannoisian of France and *P. anglica* Newton,¹⁴ from contemporary and also somewhat later beds in the Isle of Wight, are also of large size and have thin vertebrae, and *P. colenutti*¹⁵ (a maxilla from the Sannoisian of the last locality) is probably also a member of this group. In this country these large forms are found only in the Bridger. As well as the two types discussed above, *P. laevis* and *P. sclerops* of Cope¹⁶ are probably of this type. Ameghino¹⁷ has named "*Pappichthys*" *patagonica* from the Patagonian formation,

¹⁰ Bull. Soc. Geol. Franc 4, ser. II, 485-488, pl. x, 1901.

¹¹ Contrib. Cand. Paleont. 3, 3, 1891.

¹² Bull. Com. Geol. Petrograd 34, 487-507, 1915. This work is not available to us.

¹³ Ann. de Paleont., 6, 33, 1911.

¹⁴ Op. cit., 3-8, pl. i. See also Leriche, Bull. Soc. Belge Geol. 22, 121, etc., 1908.

¹⁵ Op. cit., 8-9, pl. i.

¹⁶ These were first described in 1873, figured with full descriptions in 1884, pp. 58-60, pls. iii, iv.

¹⁷ Ann. Mus. Buenos Aires, 15, 183.

but he does not describe it; the specimen is an apparently indeterminate jaw fragment of small size associated with marine forms. It is probably not an amiid.

While these large forms seem to have become extinct at an early date, there are a number of middle Tertiary forms which are certainly of the true *Amia* type, of "normal" size and body structure. These include several European forms: *A. ignota* of the Sannoisien, discussed above, and *A. mynieri* Priem from the same stage;¹⁸ *A. longistriata* and *A. oligocaena* Winkler from the Oligocene (Stampian?) of Prussia; and finally in the Aquitanian (Lower Miocene), *A. valenciennesi*, mentioned above, in France, *A. macrocephala* Ruess¹⁹ from Bohemia, and *A. kehreri* Andrae²⁰ from Germany. In most of these the body shape is quite clearly that of *Amia*. These forms are not found in Europe later than the Lower Miocene. In this country the body shape is known in only two forms represented by fragments from the "Amyzon shales" (Florissant) of the Miocene of Colorado, *A. dictyocephala* and *A. scutata* Cope.²¹ Both are clearly of the *Amia* type.

There remain a number of forms which are known almost entirely through isolated vertebrae which are of comparatively small size and not thin antero-posteriorly. Such forms include *A. barroisi* and *A. lemoinei* of Leriche²² from the Sparnacian²³ of Epernay, the former being reported also from Russia;²⁴ and *A. eocena*, described by Owen²⁵ as a lizard, from the lower Eocene of Suffolk²⁶ as European representatives. It is highly probable from the "circumstantial evidence" that they belong to *Amia*. In this country these problematical small forms include *A. depressa* and *A. newberriana* of

¹⁸ Op. cit., 34-37. In his figure 40, Prime's "inferior postorbital which tends to divide in two" probably includes both postorbital elements, and his superior postorbital is the "squamosal," while the supposed "squamosal" and postfrontal are probably parts of the frontal and parietal. In a specimen of *A. calva* in our possession the two postorbital plates are fused on one side, separate on the other.

¹⁹ Best described by von Meyer, *Palaeontographica*, 2, 61, pls. viii, ix, 1851.

²⁰ Figured in Abh. Senckenb. Naturf. Ges. Frankfurt, 18, 359, pl. i, 1894.

²¹ Bull. U. S. Geol. Surv. Terr. ser. 2, 1, 3, 1875; op. cit., 745, pls. lix, lx, 1884, and Hussakof, Bull. Amer. Mus. Nat. Hist., 15, 60, fig. 29, 1908.

²² Ann. Soc. Geol. Nord., 29, 173-196, 2 pls., 1899.

²³ Cf. Priem, Bull. Soc. Geol. France, 4 str. 11, 477, 501.

²⁴ Stoyanow, op. cit.

²⁵ Fossil Reptiles of the London Clay, Mon. Paleontogr. Soc., 1850, pt. 2, 50, pl. 14. This is a jaw fragment.

²⁶ Leriche, Bull. Soc. Geol. Nord., 36, 167, 1907.

Marsh,²⁷ *Protamia media*, *P. gracilis* and *Hypamia elegans* of Leidy²⁸ and "*Pappichthys*" *corsoni* and *P. symphysis* of Cope,²⁹ all from the Bridger; and *A. whitacesiana* and *A. macrospondyla* Cope³⁰ from the Miocene of Canada. Some of these types may very well be relatives of our form, but we know of no method at present of distinguishing them from forms representing the ancestors of *Amia*.

Paramiatus gurleyi thus stands at present without known close relatives. It seems to represent a sterile side branch of the Amiidae which had begun to assume the deep-bodied type attained successively by various actinopterygian groups in almost every period since the origin of this subclass.

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²⁷ Proc. Acad. Nat. Sci. Phila., 105, 1871.

²⁸ Fully described and illustrated in 6th Ann. Rept. U. S. Geol. Surv. Terr., 188-189, pl. xxxii, 1872 (1873).

²⁹ Fully described in op. cit., 1884, 57-60, pls. iii, iv.

³⁰ Op. cit., 2, pl. i.

THE LATTICE DIMENSIONS OF SPINEL (MgAl_2O_4).

E. POSNJAK.

Two of the very early determinations of crystal structure were made on some of the spinel group of crystals. Thus W. H. Bragg¹ studied the X-ray diffraction effects from magnetite and mentions that "the results for spinel MgAl_2O_4 work out in exactly the same way." At about the same time S. Nishikawa² also studied both magnetite and spinel and, on the basis of the Laue diffraction method, determined their crystal structure, which led to the same conclusions as were obtained by W. H. Bragg. Both papers represent a brilliant and classical example of interpreting X-ray diffraction effects. They established the crystal structure of magnetite and spinel, which is a type of structure since encountered in many other crystals³ and now known as the "spinel type" of structure. While the structure of spinel is thus well known, there are no data in respect to the lattice dimensions of spinel (MgAl_2O_4) itself, as neither W. H. Bragg nor Nishikawa has determined it. These data are given in the present paper and were obtained for comparison purposes with other substances, the structures of which are now being investigated.

The spinel used was prepared by heating a mixture of aluminum oxide and magnesium carbonate in the right proportion to about 1700° . The resulting sintered product was fine-grained and isotropic and had a refractive index of 1.717 ± 0.002 ,⁴ which agrees with the value given by G. A. Rankin and H. E. Merwin⁵ for pure artificial spinel.

The diffraction apparatus used was one made by the General Electric Company⁶ in which the distance between the sample and photographic film is eight inches. The radiation used was $\text{K}\alpha$ of molybdenum. The spacings were standardized with sodium chloride.

Spacing measurements of the diffraction lines recorded on the photographic film are given in the first column of Table I.

¹ Phil. Mag., 30, 305, 1915.

² Proc. Tokyo Mat.-Phys. Soc., 8, 199, 1915.

³ Dickinson, R. G., Jour. Am. Chem. Soc., 44, 774, 1922. Wyckoff, R. W. G., Jour. Am. Chem. Soc., 44, 1994, 1922.

⁴ I am indebted to Mr. G. Tunell for this determination.

⁵ Jour. Am. Chem. Soc., 38, 572, 1916.

⁶ W. P. Davey, Gen. Elect. Rev., 25, 565, 1922.

The estimated relative intensities of these lines (giving the strongest line the value of ten) and the squares of the sines of their angles of reflection are given in columns 2 and 3. It is well known that the ratios of the $\sin^2\theta$ should give for a cubic crystal values of whole numbers, which are usually small. As will be seen from the values given in Column 4, this is the case within the limits of the experimental errors. These whole numbers represent the sum of ($h^2 + k^2 + l^2$) and serve to assign the indices of the planes producing the diffraction lines; these are given in column 6. In the last column is given the value of the length of the edge of the unit cube calculated from each observed diffraction line.

TABLE I. Powder diffraction data from spinel (MgAl_2O_4).

d n	Estimated intensity	$\sin^2\theta$	Ratios of $\sin^2\theta$	$h^2 + k^2 + l^2$	Indices	a_0
4.60	6	0.00595	3.05	3	111(1)	7.98
2.835	6	.01567	8.02	8	110(2)	8.01
2.425	10	.02141	10.97	11	113(1)	8.04
2.320	0.5	.02340	11.98	12	111(2)	8.04
2.005	8	.03134	16.06	16	100(4)	8.02
1.638	2	.04690	24.01	24	112(2)	8.03
1.545	8	.05275	27.00	27	{ 111(3) 115(1)	8.03
1.420	9	.06248	32.00	32	110(4)	8.04
1.359	1	.06820	34.92	35	135(1)	8.04
1.268	1	.07825	40.08	40	130(2)	8.03
1.222	3	.08435	43.18	43	335(1)	8.02
1.159	2	.0938	48.03	48	111(4)	8.04
1.123	1	.0998	51.10	51	{ 155(1) 117(1)	8.02
1.071	2	.1098	56.20	56	123(2)	8.02
1.045	4	.1153	59.05	59	{ 355(1) 137(1)	8.03
1.003	3	.1259	64.40	64	100(8)	8.03
0.945	1	.1411	72.25	72	{ 110(6) 114(2)	8.02
0.928	3	.1463	74.90	75	{ 111(5) 157(1)	8.03
0.898	2	.1562	80.00	80	120(4)	8.03
0.842	2	.1778	91.05	91	139(1)	8.03
0.820	4	.1874	95.90	96	112(4)	8.03
0.789	1	.2024	103.7	104	{ 134(2) 150(2)	8.04
0.777	2	.2086	106.8	107	{ 159(1) 377(1)	8.04

$$a_0 = 8.03 \pm 0.01$$

In the spinel structure eight molecules are associated with the unit cell. Introducing this value in the well-known equation

$$\rho = \frac{Mm}{a_0^3}$$

where ρ is the density, M the mass of the spinel molecule, m the number of spinel molecules within the unit and a_0^3 the volume of the cube, we find for the density of spinel the value 3.628. This agrees within two per cent with E. Dufau's⁷ value, 3.57 which was obtained on synthetic material. Natural spinel, according to Dana,⁸ varies in density from 3.5 to 4.1, which is due largely to isomorphous replacements.

In conclusion it may be of interest to note that the apparent discrepancies, to which S. Nishikawa⁹ calls attention, between the observed intensities of the reflections from the (111)-plane, and those expected from the assigned structure, are not real. As may be seen from the "powder method" diffraction data in Table I, the intensities of both reflections, 111(1) and 111(3), are strong, while 111(2), is very weak in complete agreement with Nishikawa's calculations.

SUMMARY.

Diffraction data were obtained from artificial spinel by the "powder method." The length of the edge of the unit cube containing eight molecules of $MgAl_2O_4$ is 8.03 ± 0.01 . The calculated density of spinel is 3.628.

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⁷ Bull. Soc. Chem., 25, 669, 1901.

⁸ Dana, System of Mineralogy.

⁹ Op. cit., p. 208.

PHYLOGENY OF THE DEER.

F. B. LOOMIS.

The modern representatives of this phylum, and the fossil representatives to a considerable extent also, have been largely classified on the peculiarities of the antlers. At best the antler is a variable structure; and, with the exception of the reindeer, is present on the males only, beside which there is a considerable group of antlerless forms. In this last group it is not easy to distinguish deer from antelopes, bovids, and gazelles, though, as I have shown in a previous paper,¹ the manner of forming the fourth upper premolar is different in each of these groups. Using the principles developed in the above mentioned paper, I shall here undertake to show that, while the teeth of deer have been formed on the same general plan as those of oreodonts and all other selenodonts; still there are peculiar modifications of the fourth upper premolar distinctive of the deer, even among the antlerless forms; that the deer have been a polyphyletic group; that there is a close relationship with the giraffes and sivatheres; and will try to separate the early deer from the early representatives of the antelopes, bovids, etc.

The development of the four-cusped selenodont upper molar tooth of the deer follows the same methods as in oreodonts. *Amphitragulus* may illustrate this. Premolar 2 is as simple as any found in this family, a single cusped tooth with the primary cusp in the middle of the tooth. From this a crest runs forward which, as it develops, is seen as the anterior outer cusp (anterior crest of selenodonts) of molar 1. A second ridge runs to the rear, and corresponds to the posterior outer cusp (posterior crest) of the molar. On the inside there are two cingula developed, the anterior one making the anterior internal cusp (anterior crescent), while the posterior cingulum corresponds to the posterior internal cusp (posterior crescent). This much is characteristic of all selenodonts. In the deer group it is further characteristic that the posterior crescent is the longer, and the rear end of the anterior crescent overlaps it. In the forming of premolar 4 the shortening is attained by a fore-and-aft compression, both the anterior and posterior crescents being retained, but shortened, the prolonged anterior end of the posterior crescent projecting into the basin of the

¹ Bul. Geol. Soc. of Amer., 36, 591, 1925.

tooth. This is the distinguishing feature of the deer dentition and is seen on all the upper dentitions, unless too much worn down. In the later or more progressive forms the anterior premolars progressively acquire the character of the fourth premolar, as shown in Fig. 1.

In the case of the lower dentition, the primitive tooth, or first premolar, has a high median, or primary cusp. As in the upper dentition the anterior slope, or ridge, makes the anterior external cusp of the molar, but in this case the external cusps become curved, so as to appear similar to the inner cusps of the upper teeth. In like manner the posterior ridge makes the posterior external cusp or crest. In deer (and antelopes) there

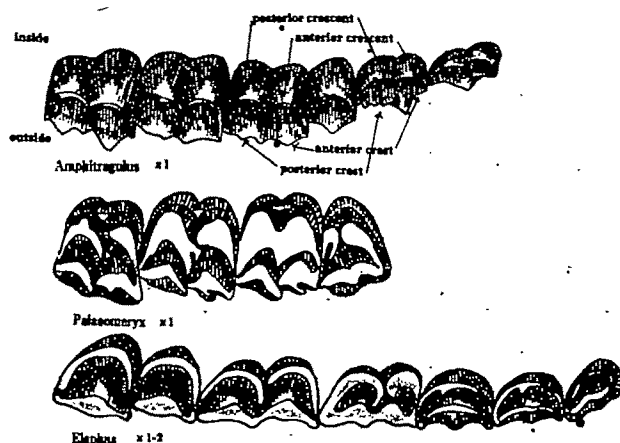


Fig. 1. Three upper dentitions to show the mode of formation of the molars from the premolar type, and the typical shortening of premolar 4.

are transverse ridges on the premolars, running toward the inner side. The most prominent of these is the median one which, as it increases in size and unites with the developing internal cingula, seems to spread front and rear to make the anterior inner and posterior inner cusps, or crescents. In some of the more primitive deer, like *Lophiomeryx*, these crescents are still incomplete on the molars; so that there is but little to distinguish the first molar from the fourth premolar. In general while the fourth premolar may become quite molariform, the more anterior premolars do not take on its character.²

² In the case of all illustrations the upper dentitions are those of the left side, and the lower dentitions those of the right side; so that in case the relationship of uppers to lowers is desired a tracing of the lower can be put directly over the upper series and the occlusion be immediately apparent. Also in all figures the inside of the tooth is above and the outside is below.

The method of forming the fourth upper premolar, as described above, was first recognized by Rüttimeyer,⁸ and he also recognized that the premolar teeth offered the best clues for the study of this group; but he emphasized especially the deciduous dentition. These milk teeth do confirm the manner in which the molars have been derived from the simplest premolars; but, while they have the fundamental characters of the adult dentition, they have peculiarities of their own, which are neither recapitulatory nor prophetic, but represent specializations to the needs of the young.

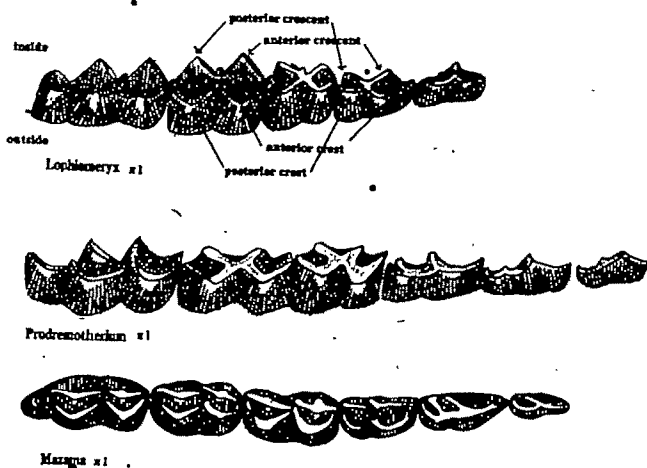


Fig. 2. Three lower dentitions to show the mode of formation of the molars from the premolar type.

Typical deer have antlers, structures so peculiar that it is most improbable that they originated more than once. Thus we must feel that all the antlered genera were derived from a common stock, and that the differences among them have been acquired since the acquisition of the antlers.

Among the antlered deer there are two distinct types of dentition, the two groups being most easily recognized by peculiarities in the lower dentition, though there are also characteristic peculiarities in the upper teeth. One group, the more primitive one as far as the dentition is concerned, has the posterior crest of the lower molars more or less completely isolated, and the same is true for the anterior crescent. This is due to the

⁸ Beiträge zu einer Naturischen Geschichte der Hirsche, Abh. der Schweiz, Paläont. Gesellsch., 10, 6, 1883.

more or less complete fusion of the anterior crest with the posterior crescent. The reindeer (*Rangifer*) shows this in a most striking manner both on the molars and premolars, but *Alces* has it almost equally highly developed. This cross-over character is seen clearly as early as *Dicrocerus* in the middle Miocene. It is also seen in such genera as *Axis*, *Rusa*, *Odocoileus*, and *Mazama*, though in the last two mentioned genera it is not so completely developed (see *Mazama* in Fig. 2). In its less marked development it is still characteristic of many of the antlerless genera such as *Amphitragulus* and *Prodeumotherium* (Fig. 2) and also in *Palaeomeryx*, *Micromeryx*, *Hyaemoscus* and *Lophiomeryx*. It is present too in *Dremo-*

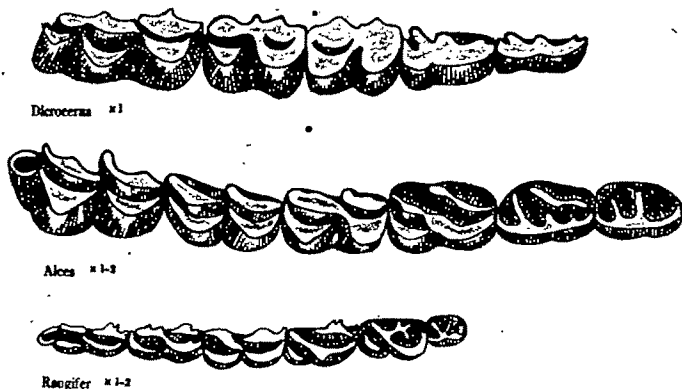


Fig. 3. Lower dentitions showing the cross-over, characteristic of the more primitive deer.

therium, *Dorcatherium* and *Hydropotes* but with slight modifications, so that I consider these three genera to represent a side line of early and antlerless deer.

The upper dentition of the group which has the typical cross-over in the lower teeth is peculiar in that the rear end of each of the crescents on the molars is bifurcated. This may appear as a simple split as in *Dicrocerus* (Fig. 4) or as a more marked notch as in *Alces*. In some stages of wear this notch may appear as a pit in the rear of the crescent, as in the case of the anterior crescent of molar 1 of *Alces* (Fig. 4). In the case of *Rangifer* the bifurcation is obscured by the one end of the split being elongated and the other end appearing as a small spur well forward from the rear of the crescent. These bifurcations may and do appear in the modified fourth pre-

molar or in others of the premolars. The genera *Axis*, *Rusa*, *Mosama* and *Odocoileus* also show this character well, while the early and antlerless genera, *Amphitragulus*, *Prodremotherium*, and *Palaeomeryx* show it in a little less marked condition. The three genera which were mentioned as a side line are peculiar in not having the bifurcation, which is the main reason for considering them as aberrant.

In contrast to the above group of deer stands another section of the antlered deer, in which the lower molars, though having originated in the same way, have lost the cross-over character, the two outer crests uniting with each other and the two crescents doing the same (see Fig. 5). This I take to



• Fig. 4. Upper dentitions to show the bifurcation of the posterior ends of the crescents.

be less primitive as I do not find it in the antlerless genera, and it is not the simplest development to be expected from the mode of origin of the lower molars. It however is established in the middle Miocene genus *Blastomeryx*.⁴ Closely related to this genus is the upper Miocene and Pliocene genus *Merycodus* of America, with which is also allied the European deer, *Elaphus*. The rather aberrant genus *Cervulus* also has the same type of dentition.

These same genera are distinguished as a group by having the rear ends of the crescents on the upper teeth, simple; i. e.

⁴ *Blastomeryx*, as here used, is the genus defined by Matthew and includes such species as *B. primus*, *B. adventa*, and *B. orcotti*. Matthew, W. D., Bul. Amer. Museum Nat. Hist., 24, 535, 1908.

they lack the bifurcations so characteristic of the previous group.

The typically antlered deer are disposed of as belonging to one or the other of the foregoing groups. There remains



Blastomeryx x1



Merycodas x1



Elaphus x1-2

Fig. 5. Lower dentitions showing the tendency for crest to unite with crest, and crescent with crescent.

however that strange form known as *Sivatherium*, along with its less well known relatives, which has antlers very suggestive



Blastomeryx x1



Merycodas x1

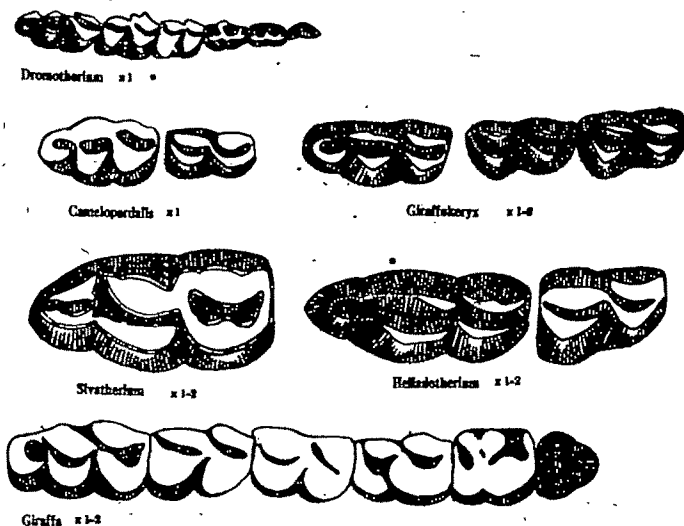


Elaphus x1-2

Fig. 6. Upper dentitions showing the rear ends of the crescents simple instead of bifurcated.

of those of *Alces*. *Sivatherium* has usually been treated as though close to the giraffes. This I can not see. First, the antler is a structure so peculiar, that it is hard to conceive of it as being developed more than once. And second, when we

compare the build and general outline of *Sivatherium* with that of other animals, it has the character of that of the moose (*Alces*) rather than that of a giraffe. •The lower dentition of *Sivatherium* (Fig. 7) is distinctly of the cross-over type as in the moose and reindeer. The upper teeth also correlate with those of *Alces*, differing however in that the posterior portion of the crescents is thickened, so that their bifurcation is obscured. The bifurcation is however indicated by the outer



• Fig. 7. Lower dentitions of giraffes and *Sivatherium* for comparison with the *Alces*-*Rangifer* group.

spur of the anterior crescent connecting with the posterior crescent; while the inner spur projects into the basin of the tooth. The general association of this form with giraffes has its basis in dental resemblances, but I shall show that giraffes are also derivatives of the same group of deer as the one from which *sivatheres* came; so that the relationship is to a common ancestor rather than to each other.

The giraffe group does not have antlers, but does have a longer or shorter bony process (which may be lacking as in *Helladotherium*) projecting above the orbit, and in the same position as that occupied by the antler. This differs from an antler in not being shed annually, and in being covered with skin. All of the giraffe group have the molars and premolars of the lower dentition strikingly similar to those of the *Dicro-*

cerus-Alces-Rangifer group of deer, with the distinctive cross-over of the anterior crest to the posterior crescent (Fig. 7). The posterior crest is typically isolated, and the anterior crescent tends toward isolation, but does not go as far as in the case of *Alces* or *Rangifer*.

On the upper teeth of giraffes the posterior portions of the crescents are swollen; but in the less worn, or unworn teeth,

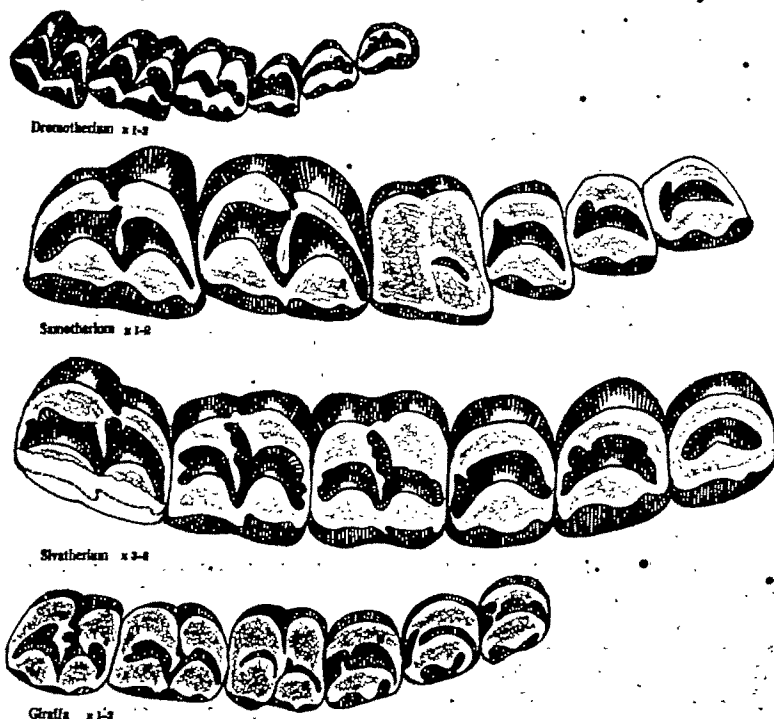


Fig. 8. Upper dentitions of giraffes and Sivatherium for comparison with those of the *Alces-Rangifer* group.

the bifurcation of the rear ends of the crescents is apparent (see *Giraffa*, Fig. 8). *Samotherium* seems to be peculiar in that the process extending into the basin of each molar appears to be the rear of the anterior crescent. This I think, however, is an illusion, the process being really the anterior part of the posterior crescent, as would be normal. The apparent separation of this process is due to the extreme development of the notch into the posterior crescent, which while developed to a

lesser degree, is present in all the other giraffes. This fundamental relationship of giraffes to the deer was recognized by Rüttimeyer⁶; but since his time it has been customary to place them in a more or less isolated group. They must have separated from the deer phylum in the early Miocene, just about the time the antler was being acquired. The giraffes acquired bony processes but never went the length of having them deciduous. The processes are long to short in samotheres, short in giraffes, and lacking (lost) in helladotheres. Besides these better known genera there are several others from India and Greece which so far are known mostly from the dentitions only. The group is represented by forms from the Pliocene, Pleistocene, and Recent times, in Europe, Asia and Africa.

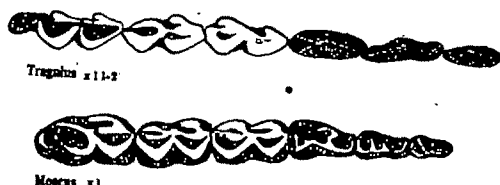


Fig. 9. Lower dentitions showing the peculiar inner lobe.

In the middle and upper Miocene of America occur two closely related, and peculiar genera, *Dromomeryx*⁶ and *Aletomeryx*.⁷ They are very close to each other in relationship. Both genera are peculiar in having bony processes over the orbits, which were covered with skin and were not shed annually. The tips of these processes are not known in *Dromomeryx*, but they were swollen in *Aletomeryx*. The dentition of both genera is strikingly like that of the giraffes on the one side, and like that of *Palaeomeryx* (as Douglas pointed out) on the other side. I can not but take these genera to represent the intermediate representatives between the early deer and the giraffes. They are just the sort of forms one would have postulated as required for such intermediate position, and occur at the time when there is a gap in the series.

Tragulus and *Moschus* are two peculiar antlerless forms, which have on the inner side of the lower molars a most

⁶ Loc. cit., p. 35.

⁷ Douglas, Ann. Carnegie Museum, Vol. 5, 457.

⁸ Lull, This Journal, 50, 83, 1920.

[illegible]

Fig. 10. Phylogeny of the deer.

In Fig. 10 I have attempted to represent the phylogenetic relationships of all these forms of deer. We do not know the Eocene ancestor of the group, but the phylum must run back into that period. During the Oligocene all the representatives were small, antlerless, and lived in Europe. *Gelocus* closely resembles the deer, but is highly specialized for a deer of that time, so it is here regarded as a side line. The less modified members of this Oligocene group continued on into the Miocene as *Dremotherium* and *Dorcatherium* and it is still represented by the chevrotains and *Hydropotes*. These give us a picture of the earliest deer, but have, in the long time since

early Miocene, acquired some peculiarities of their own. The long canines seem to be relics of similar structures in the early deer, where they are quite general. In the early Miocene a group of deer, generally larger, and represented most typically by *Palaeomeryx*, began the acquisition of bony processes over the orbits. In part of them these processes remained simple and were covered with skin, and this group leads to the giraffes. Curiously the first giraffes are represented by American genera, but by the end of the Miocene they disappear from the American continent, and continue their record in Asia, Europe and Africa. This line reaches its maximum in the Pliocene in samotheres, helladotheres and true giraffes. The living representatives of the group are but a remnant of an over-specialized group. Again in the early Miocene other forms developed the bony process over the orbit to a greater extent, and acquired that strange habit of having the major part of the bone die and become an exposed dead bone. This then began to be shed and a new one grown to replace it, and we have to deal with the antler proper. In *Dicrocerus* the antler is relatively simple, but rapidly acquires all sorts of modifications, like multiple branches, flattening, etc., until in its extreme it makes those over-developed structures like the antlers of a moose *Alces* or reindeer. This group has spread, especially during Pliocene times, from Europe to Africa, Asia and the two Americas. Early in the Miocene some of the deer, with many-branched antlers, separated off to one side and gave rise to the typical genera *Blastomeryx*, *Merycodus*, and *Elaphus*.

All the above forms I believe are true deer. In addition to them there are a considerable number of antlerless genera which have been associated with the deer at one time or another. While going over the camels, antelopes, bovids, and sheep, as well as the deer, it has become necessary to arrive at some conclusions as to such genera, before I could decide not to include them in the deer. These may be mentioned, but with the understanding that they are tentative, and given simply to show why these genera are not included in the deer phylum.

Xiphodons and caenotheres are bunoselonodonts in their affinities and this group is as far away from deer as any artiodactyl can be. *Hypotragulus* and *Nanotragulus* are clearly early representatives of the bovid line, to which group *Leptomeryx* may also belong, but it is not so clearly marked.

Hypisodus is a gazelle. *Protoceras* belongs with the camels. *Capromeryx* and *Antilocapra* are close to each other, but I have not yet been able to place them definitely, except that they are not deer.

The above study has been primarily based on dentitions, but the other structural characters have been taken into consideration. It associates some forms which have been considered as in different groups, and separates several forms which have been thought close to each other; but I am confident that the teeth offer fundamentally safe characters, while the antlers do not.

AMHERST COLLEGE,
AMHERST, MASS.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

How's and Whys of Cooking; by EVELYN G. HALLIDAY and ISABEL T. NOBLE. Pp. xii, 179; 40 figs. and frontispiece in color. The University of Chicago Home Economics Series. Chicago, 1928 (University of Chicago Press, \$2.00).—This is not a cook-book and it is not a book on the chemistry of cooking, but it is rather a discussion of the effect of various factors such as time, temperature, hydrogen ion concentration (or acidity), mechanical treatment and composition on the quality of cooked foods. There are some excellent illustrations showing the effect on the product caused by varying some of the factors, and there are some recipes. Altogether, the book strikes one as being excellent for anyone of intelligence who wishes to understand the principles of cooking. Doubtless, the book will be used in home-economics courses, but equally it should be of interest and value to the intelligent cook.

H. W. FOOTE.

Engineering Chemistry; Sixth Edition, by THOMAS B. STILLMAN. Revised and enlarged by ALBERT L. STILLMAN. Pp. xv, 1093, with 235 illustrations. Easton, Pa., 1925 (The Chemical Publishing Co.).—This is the sixth edition of the late Professor Thomas B. Stillman's well-known book, revised and enlarged by Albert L. Stillman.

The present reviewer believes that this book has never borne a suitable title, nor can he subscribe to the statement in the Foreword which reads: "Engineering Chemistry is that branch of the Science that treats of methods of analysis of materials used in engineering." Differences of opinion, however, are not limited to horse trades, presidential campaigns and lawsuits. When the American Chemical Society gets through telling the chemical engineers of the country what Chemical Engineering is, one may hope that it will then define Engineering Chemistry, which is, presumably, some kind of chemistry if not, indeed, all kinds of chemistry.

To quote the author, the present volume "is in effect a manual of testing of materials to determine their use or lack of availability in industry. To this end actual chemical analyses must be supplemented by physical tests and microscopic examination. In this volume all these methods have been described, especially when standardized, and their relation to each other outlined." Now, of course, no single volume of about eleven hundred pages could possibly describe *all* the methods of testing engineering materials and it is of interest to note what particular engineering materials or classes of materials have been chosen for treatment. Chapter headings give this information, and are as follows: Testing and Analysis of Ores; Testing and Analysis of Stone, Clay, Brick

and Cement; The Testing and Examination of Metals and Alloys; Solid Fuels; Gas Analysis; Oils or Liquid Hydrocarbons; Analysis and Testing of Soap, Cleaning Compounds and Grease; Paint and Varnish Testing; Water Analysis; The Physical and Chemical Examination of Paper; Appendix. The Appendix contains three tables and, curiously, schemes for systematic analysis of cylinder deposits; of a cyanide mixture, and of dynamite. It is perhaps fortunate, since this professes to be a textbook for students, that the analysis of dynamite comes last.

Now it must be said that not all or even a majority of engineering materials have been included in the foregoing list. If the author had admitted in the beginning that he was going to talk about a few of the very many materials used in engineering, and make such choices as pleased his fancy, one might forgive him for a chapter on paper with no mention at all of rubber as an engineering material, etc., etc., etc.

At many places in the book one meets statements which are wrong or misleading. Thus, to give only one example, on page 960, "Engineers are interested in water supply from two standpoints: 1. Water for steam purposes. 2. Water for drinking purposes." This is very far from being the case, as every chemical engineer knows.

While not all obsolete material has been eliminated, this revised edition is, indeed, a modern textbook. The tests described are compiled from many sources, but a large number, possibly half of all, are taken directly from A. S. T. M. publications and one may question the need of republishing them here. The book is profusely illustrated but, unfortunately, many of the illustrations are blurred and indistinct. Also, a number of them might have been omitted without detracting from the value of the book, notably such as Fig. 11 (a spectroscope); Fig. 66 (a Büchner funnel); Fig. 90 (Orsat); etc.

One might go on for some time pointing out faults but too much has perhaps been said of these and too little of the merits of the book. It will certainly prove a useful reference book to all who have occasion to test such engineering materials as are given place in the author's list. And since most of the tests described are taken frankly from such sources as the A. S. T. M. publications, U. S. Bureau of Mines and U. S. Bureau of Standards bulletins, etc., they are probably the best available.

And, finally, an expression of appreciation is surely due the junior author for undertaking and accomplishing the long task of revising and modernizing a book which has had so long and honorable a period of service.

HARRY A. CURTIS.

The Crystal Detector.—The various attempts which have hitherto been made to explain the action of a crystal rectifier in terms of gas layers, unidirectional resistance, thermoelectric effect, electrolytic action, etc., have not been accepted as wholly satisfactory.

A new explanation now offered by W. OGAWA is based on the following experiment: A pair of electrodes consisting of a copper rod and a galena crystal were sealed in a tube with a short intervening space between them and the tube evacuated. A polarity detector consisting of a NaSO_4 solution containing phenol-phthalein was placed in series and an A. C. potential applied to the electrodes. When the potential was sufficient to produce a glow discharge the solution indicated a rectified current which was in the same direction as that given by a contact rectifier consisting of the same materials. This result was ascribed to the difference of electron emissions from the cold electrodes, as other effects such as the thermoelectric or the electrolytic effect cannot be present.

Many couples of different metals and crystals were tested in this manner to see which gave the stronger electron emission. It was found that they could be arranged in a series with magnesium at the head and that this series was in general agreement with their order as determined when used as crystal detectors.

The author accordingly adopts the view that the two rectifications, namely that in the vacuum tube with separated electrodes and that of the crystal rectifier, are essentially identical in principle, the only difference being in the distance between the electrodes and the surface areas from which the electron emissions occur.

If we consider the position of the electrodes in the crystal rectifier their separation will vary from contact to a wider space involving the ordinary atmosphere. Thinking of it microscopically the lattice constant of metals is of the order of $6(10)^{-8}$ cm. and the separation of the gas molecules at normal pressure about $3(10)^{-7}$ cm. A free space of from $6(10)^{-8}$ to $60(10)^{-8}$ cm. will hardly allow the entrance of gas molecules and consequently free electron emission may be possible where interstices of this magnitude occur; and further, since the mean free path of the electron in the atmosphere at normal pressure is $9(10)^{-5}$ cm. the electrons may reach the opposite electrode without collision with gas molecules in a space far wider than $60(10)^{-8}$ cm.

On this view electron emission in the free spaces of a crystal rectifier occurs in the highest vacuum and no ionization of gas molecules is involved. As the points of actual contact make a path for current leakage it is evident that a proper value of resistance is of prime importance in a crystal to be used as a detector.—*Phil. Mag.* 6, 175, 1928. F. E. B.

Beyond the Electron; by Sir J. J. THOMSON. Pp. 43. Cambridge, 1928 (Cambridge University Press).—The distinguished discoverer of the electron in this, the first lecture of a new series to be known as the Founders' Memorial Lectures at Girton College, undertakes to show that in the light of newly discovered properties the electron is not a simple point charge of negative electricity but even when moving uniformly possesses a structure in its immediate surroundings, or in other words, is accompanied

by a series of waves. The evidence of this appears from the experiments of G. P. Thomson on the diffraction effect obtained when a thin pencil of rays (electrons) was passed through an exceedingly thin sheet of metal and an alteration of the pattern was produced by bringing a magnet near the photographic plate on which the result was recorded. The lecture is occupied with consequences of the view that these accompanying waves carry the electron along and determine the way it is to go. It may be further noted that this theory, which is essentially a physical one, leads to some rather remarkable coincidences with the theory of wave mechanics which has been developed by de Broglie, Schrödinger, and others, on purely analytical grounds. F. E. B.

Experimental Science for Junior Technical Students; by J. W. BISPHAM. Pp. 100, figs. 50. Oxford, 1928 (Oxford University Press, \$70).—This booklet is designed for use with evening classes of youths engaged in or about to enter trades in which a knowledge of some of the principles of Mechanics and Heat will be valuable. It contains a variety of experiments and discussions presumably within the grasp of the intelligent artisan and capable of greatly increasing his comprehension of the properties of matter, the function of machines and the application of thermal phenomena. F. E. B.

Vestiges of Pre-Metric Weights and Measures; by ARTHUR E. KENNELLY. Pp. 189. New York, 1928 (The Macmillan Company, \$2.50).—The author of this book has presented the result of a year's investigation in Europe aided by the Bureau of International Research, on how far the names and instances of the use of pre-metric measures have persisted in the principal European countries, excepting Russia and Turkey. As was to have been expected, persistent remains of the older usages were found in all metric countries but in greatly differing degree. In France and Germany these vestigial remains are relatively rare, while in Spain and Italy they may be encountered more frequently.

As opinions in America vary greatly as to the existence and importance of these residual measures in metric-using countries, the aim of the author was primarily to raise the question from the plane of controversy to one of statistical enquiry, a purpose which he has successfully accomplished. His results are also important as indicating how long or short a time it is likely to take a country adopting the metric system to bring it into general use. F. E. B.

Visual Lines for Spectrum Analysis; by D. M. SMITH. Pp. 34. London, 1928 (Adam Hilger).—All who wish to use the spectrometer for the identification of the metals either as constituents of compounds or as minute impurities will be greatly indebted to the author for this new set of tables in convenient form. The distinctive and sensitive lines (i. e. lines which appear in the spectrum when only small quantities of the metal are present) have

been investigated and reported for 52 elements. Various matters of practice and technique, which he also explains, add greatly to the usefulness of the book.

F. E. B.

Mechanics for Engineers; by JULIAN C. SMAELWOOD and FRANK W. KOUWENHOVEN. Pp. viii, 185, figs. 204. New York, 1928 (D. Van Nostrand Company, \$2.50).—This work by two members of the Johns Hopkins faculty is commended to the attention of teachers desiring a text for use with engineering students. It contains many admirable features, notably clearness in statement of principles, a wealth of illustrative problems, and a topical treatment which makes it admirably adapted to class-room work. In a field already fully occupied, this work merits and should win distinctive recognition.

F. E. B.

The Electrical Conductivity of the Atmosphere and Its Causes; by VICTOR F. HESS. Pp. xviii, 204, figs. 15. New York, 1928 (D. Van Nostrand Company, \$4.00).—This work is a translation from the German edition of 1926, by L. W. Codd, with the exception that the rapid development of the subject has required a rewriting by the author of the chapter on the so-called cosmic or ultra-gamma radiation and the one on the properties of the upper atmosphere. The character of its contents is well indicated by the chapter subjects, namely: Fundamental Facts as to Atmospheric Conditions; The Conductivity of the Atmosphere; The Ionizers of the Atmosphere; Processes which Result in the Destruction of Ions; and The Ionization Balance of the Atmosphere. For the benefit of readers who do not bring a sufficient preliminary understanding of the associated phenomena, explanatory sections are introduced at appropriate places dealing with the laws of gaseous ions, conductivity of gases, and the fundamentals of radioactivity. The special student of the subject will find the book a satisfactory compendium of methods and well-documented results, by an authority who for some time has been actively engaged in investigation in this field.

F. E. B.

GEOLOGY.

Pre-Devonian Paleozoic Formations of the Cordilleran Provinces of Canada; by CHARLES D. WALCOTT. Cambrian Geology and Paleontology, Vol. 5, No. 5. Smithsonian Misc. Coll., vol. 75, No. 5. Pp. iii, 175-368; pls. 26-108, text figs. 24-35, 1928.—Secretary Walcott began to do field work in the grand Canadian Rockies of British Columbia and Alberta in 1907, when he was already nearly sixty, and kept it up almost every summer for eighteen years. Three summers were devoted to unearthing the wonderful Burgess shale fauna of Middle Cambrian age, which has stirred paleontologists everywhere to admiration of these ancient creatures. This work of Walcott and others in Canada has yielded 41 formations, of which 3 are pre-Cambrian,

8 Lower Cambrian, 8 Middle Cambrian, 11 Upper Cambrian, 2 Ozarkian, 2 Lower Ordovician, 2 Middle Ordovician, 2 Upper Ordovician, 1 Silurian, and 2 Devonian. All of these excepting one have been described before, but now Walcott redefines them in the light of his entire knowledge and that of others. The book was seen through the press by Doctor Charles E. Resser, his assistant in these studies for thirteen years.

The total thickness of these Paleozoic formations is not less than 28,000 feet, of which about 16,000 feet are limestone, 10,000 feet shale, and 2,000 feet sandstone. In such a tremendous thickness, with only scattering horizons of fossils, and spread over a great geographic area in a mountainous land that is but little settled, it is but natural that, in the author's own words, the work "has been of the nature of a reconnaissance, made with the view of furnishing . . . data on the succession of the pre-Devonian fossil faunas. . . . The faunal lists accompanying the sections contain but a small fraction of the species collected."

The work is illustrated by eighty-two exceedingly fine plates, half-tones of photographs taken by the author in what is probably the grandest mountain area of marine strata anywhere in the world.

This, then, is probably the final chapter in Walcott's monumental work on the early Paleozoic of the Canadian Rockies,—the foundation on which the new generation must continue to build.

C. S.

Paläontologisches Praktikum; by O. SEITZ and W. GOTHAN. Biol. Studienbücher, VIII. Pp. iv, 173; 48 figs. Berlin, 1928 (Julius Springer, RM. 10.80 bound).—Here is a book that partially supplies a long felt need, written by members of the Geological Survey of Germany. Its main object is to stimulate and develop local collectors of invertebrate and plant fossils, and no science needs this more than paleontology. The authors did not intend their book to be exhaustive, with discussion of the methods pursued in all lands of collecting, cleaning, preserving, and labelling fossils; such a treatise is still to be written.

The "Praktikum" starts out with an account of the objects of paleontology (pp. 3-25), followed by a section dealing with the way in which fossils are entombed and what happens to them later on (26-40). This latter part is especially weak in treating of the changes that fossils undergo during pressure and chemical addition and chemical replacement. Part III deals with collecting (41-51) and Part IV with preparation in the laboratory (52-118). The second half of the book discusses fossil plants along the lines developed for invertebrates (119-168).

The book should be valuable to teachers of paleontology as collateral reading with their classes.

C. S.

Rhodesian Man and Associated Remains; by W. P. PYCRAFT,

G. ELLIOT SMITH, et al. British Museum (Natural History), London, 1928. Quarto. Pp. xiii, 76; 5 pls., 23 text figs.—In this description of the skull and other human remains from Broken Hill these very interesting human relics are studied by a number of experts from every available angle, and the result is a very complete picture of the race which is represented, its osteology, dentition, brain and potential mentality, and the peculiar diseased condition of the principal individual.

The story of the finding, its authenticity and age, are discussed by Dr. Bather in the introduction. Whatever the age of the general fossil fauna of the cave, the skull is appreciably older. The fact that with few exceptions the animals were all such as are now alive threw doubt as to the antiquity of the human relic. The above statement, together with the general Pleistocene facies of the present fauna of Africa, makes it possible to imagine a respectable antiquity for this primitive human. Just where he should be placed in the European chronology, however, is not so evident.

Cranial details point to a number of simian characters, and the skull, in spite of certain specializations, is of a relatively low type, having definite resemblance to that of Neanderthal man, with which race it had affinities. Pathologically the relic is highly interesting, due to the manifestation of dental caries and of serious lesions in the cranial wall and mastoid process of the left temporal bone. There is evidence of mastoiditis as the probable cause of individual death.

The posture was not fully erect. So peculiar was the stooping gait in fact, with knees turned out and toes turned in, that Pycraft would remove Rhodesian man from the genus *Homo* and proposes for its inclusion the new generic name *Cyphanthropus* (stooping-man), an independent development of the nascent Neanderthal stock.

The brain lies nearest that of Neanderthal man but differs in its more primitive rank. In actual size it is less than that of any known Neanderthal, except possibly the Gibraltar skull, at the same time it is appreciably bigger than that of the Piltdown man. The defective development of the brain cannot be the result of a secondary degradation, because its features conform so strictly to the primitive type. The specifically deficient areas of the brain are those which are the last to develop in the brain of a modern human child and therefore represent a stage in the evolution of the human brain.

Culturally Rhodesian man was what one would be led to expect from the implied mentality, as the associated implements are few and crude, a few chert flakes and stone balls which may have been used as bolas. These all suggest the Mousterian industry, that of Neanderthal man. One semi-vitreous clinker seems to prove the use of fire by these primitive cave dwellers. The general

appearance of both this and the next memoir to be reviewed is up to the high standard of the British Museum publications.

R. S. L.

Catalogue of the Pontian Bovidae of Europe; by G. E. PILGRIM and A. T. HOPWOOD. British Museum (Natural History), London, 1928. Quarto. Pp. vii, 106; 9 pls., 3 text figs.—This is a detailed description of the antelopes, sheep, goats, and oxen of the Pontian, Upper Miocene or Lower Pliocene of Europe, contained principally in the British Museum, together with comparative study of material in certain continental museums, principally those of Paris and Munich.

This study shows how extraordinarily difficult it is to work out a satisfactory classification of these forms, since the systematic position of many living genera is open to doubt, owing in part to parallel lines of evolution. Many fossil genera are naturally far less perfectly known, owing to the fragmentary character of the material, which greatly increases the difficulty. In all the descriptions are attempted of some 22 genera and more than 60 species and varieties, representing at least 8 sub-families. The descriptions are clear, the illustrations as ample as the material permits, and the whole points to a wonderfully rich, more or less contemporaneous ungulate fauna, comparable only to the great game assemblages in Africa to-day.

R. S. L.

Monographs of the Geological Department of the Hunterian Museum, Glasgow University. II. The Vertebrate Fossils from the Glacial and Associated Post-Glacial Beds of Scotland, and their Evidence on the Classification of the Scottish Glacial Deposits; by J. W. GREGORY and ETHEL D. CURRIE. Glasgow, 1928. Pp. 25, 3 pls., 6 figs.—The forms described are largely mammoth, rhinoceros, reindeer, red deer, urus, and horses. The age comparisons are with the Thames Valley sequence and are expressed in terms of human cultural chronology, from the beginning of the Paleolithic through the Neolithic Age. As a rule the Scottish glacial deposits rarely contain mammalian fossils and have hitherto yielded no human artifacts—it is only by such comparisons as that with the Thames Valley in this memoir that an approximate correlation can be made. It is therefore timely and of great value. A bibliography is included.

R. S. L.

Fossil Lizards of North America; by CHARLES W. GILMORE. Nat. Acad. Sci., Vol. XXII, Third Memoir, 1928. Pp. ix, 201; 27 pls., 106 figs.—In the preparation of this exhaustive memoir, Mr. Gilmore had at his disposal in the United States National Museum all of the fossil lizard remains known from North America. As a result of this research the author has redescribed and figured all of the previously known genera and species of North American fossil lizards, a total of 18 genera and 43 species. Of this number 4 genera and 5 species are synonymous. In addi-

tion there are herein described 13 new genera and 25 new species, making a total of 27 genera and 63 species, representing 6 families, of fossil Lacertilia now recorded from North America, or a total of 68 genera and 137 species from the entire world. The Mosasauridae are not included in these figures. Especially valuable are the summaries and keys to the species which accompany the descriptions of the various genera.

The table of geological distribution of Sauria in North America shows that the earliest recorded forms appeared in the Jurassic, that the greatest expansion and diversification came in the Lance, and that in the Oligocene there was a noticeable change in the lizard fauna by the introduction of many new genera, of especial importance being the first occurrence of living genera. The geographical range of these fossil Sauria extends from southern Arizona northward into Alberta, including all of the intervening states. But 5 other localities are known, viz.; New Jersey, Pennsylvania, Arkansas, California, and Oregon. The bibliography contains nearly 150 references.

M. R. T.

Illinois Geological Survey; M. M. LEIGHTON, Chief.—The following publications have been received:

Oil and Gas Development and Possibilities in East-Central Illinois; by L. A. MYLIUS. Pp. 205; 31 pls., 13 figs., with a separate folder containing maps and tables of well data. Bulletin 54, Urbana, 1927.—This publication is the result of a detailed survey of Clark, Coles, Douglas, Edgar, and parts of adjoining counties. Complete structural and stratigraphic data are given, and specific recommendations are made.

Geology and Mineral Resources of the Herscher Quadrangle; by L. F. ARTH. Pp. 120; 2 pls., 38 figs., 10 tables. Bulletin 55, Urbana, 1928.—In this bulletin an area southeast of Chicago is described in detail. The area is largely covered by terminal moraine and torrential outwash; but locally along Kankakee River early Paleozoic rocks are exposed. A part of the region is underlain by the coal-bearing Carbondale formation.

Recent Development on the Ayers Anticline; by ALFRED H. BELL. Pp. 18; + figures. Press Bulletin No. 16 (June 30, 1928).—Briefly discusses oil production and prospects in an area in southeastern Illinois.

R. F. F.

Virginia Geological Survey; by WILBUR A. NELSON, State Geologist. Bulletin 31. University, 1927. Water Resources of Virginia; by J. J. DIRZULAITIS and G. C. STEVENS. Pp. xvi, 510; 9 pls.—Presents in tabular form the complete results of stream-flow measurements made in Virginia from 1895 to 1927.

R. F. F.

Pennsylvania Topographic and Geologic Survey; by GEORGE H. ASHLEY, State Geologist. Bulletin M6. Harrisburg, 1928. Bituminous Coal Fields of Pennsylvania. Part I, Introductory

volume: General Information on Coal; by GEORGE H. ASHLEY. Pp. 241, plates and figs. Part III, Coal Resources; by JOHN F. REESE and JAMES D. SISLER. Pp. 153, plates. Part I discusses in detail the physical and chemical properties of bituminous coal and its origin, classification, and geologic occurrence. The coal-bearing stratigraphy of Pennsylvania is next outlined. A chapter on the uses of bituminous coal concludes the volume. Part III is essentially a detailed tabulation of Pennsylvania's bituminous resources by counties. Parts II and IV of this series were issued some time ago. The accompanying detailed map will be issued early in 1929.

R. F. F.

West Virginia Geological Survey; I. C. WHITE, State Geologist, DAVID B. REGER, Assistant Geologist in charge (following the death of Dr. White on Nov. 25, 1927, see vol. 15, p. 188). *Pendleton County*; by J. L. TILTON, W. F. PROUTY and P. H. PRICE. Pp. xx, 384; 80 pls., 24 figs., also 2 maps of topography (I) and general and economic geology (II) in separate cover. Wheeling, W. Va., 1927.—Pendleton County lies in the eastern part of the State, bordering on Virginia. The rocks are chiefly Paleozoic ranging from Ordovician to Carboniferous, they are much folded, the western border following the crest of the Allegheny Mountains. The region embraces extensive National Forests. Of 140,000 acres of timberland, 138,000 are virgin. The county has no railroads but much is being done in developing highways. Price \$2.50, 40 p. c. discount to teachers and Public Libraries.

Bulletin Three. The Cheat Mountain Coal Field in Randolph County. Pp. 34, with folded map. 1928.—Six prominent coal deposits give the total mineable amount as nearly 700,000,000 short tons. (Price \$1.00.)

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Toxicology, or The Effects of Poisons. Second Edition; by FRANK P. UNDERHILL. Philadelphia, 1928 (P. Blakiston's Son & Co., \$2.50). Pp. xi, 311.—This is a corrected and somewhat revised edition of a compact and exceptionally useful reference book dealing with poisons. In addition to a succinct statement regarding the occurrence and current toxicological significance of each substance discussed there are systematically arranged well compiled statements about the symptoms, fatal dose, fatal period, postmortem appearances, and antidotal treatment applicable thereto. For each poison outstanding bibliographic references are given. An introductory chapter summarizes in a "tabloid" manner the general principles of the subject.

L. B. M.

Foibles of Insects and Men; by WILLIAM MORTON WHEELER. Pp. xxvi, 217, index xi; 56 figs. New York, 1927 (Alfred A.

Knopf, \$6.00).—To those who imagine an entomologist to be only a dry uninteresting pursuer of insects, this book should prove a revelation. To the author's friends it will bring little surprise, partly because it is replete with his characteristic wit, and partly because in it he has brought together several of his papers previously printed in scientific journals. These are: the physiognomy of insects; insect parasitism and its peculiarities; a solitary wasp (*Aphilanthops frigidus* F. Smith) that provisions its nest with queen ants; a study of the guest ant *Leptoithorax emersoni* (rewritten and expanded); the ant colony as an organism; the kelep ant and the courtship of its mimic, *Cardiacephala myrmex*; the organization of research; the dry-rot of our academic biology; the termitodoxa, or biology and society. The introduction serves to tie these articles together under the title of 'foibles.' The meaning of this word has been expanded to include not only "special weaknesses of character" but such ontogenetic behavior as habits, and such phylogenetically or racially stabilized behavior patterns as 'instincts' and 'mores.' To those readers who require no entertainment the major part of the book will provide solid meat in the form of field observations upon insects. S. C. B.

Annual Report of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1927. Pp. xii, 580; many plates. Washington, 1928.—This volume contains the report of Dr. CHARLES G. ABBOT, acting secretary after the death of Dr. Walcott, since appointed secretary. (See vol. XV, pp. 184-186.) The proceedings of Board of Regents follow. The General Appendix (pp. 147-580) covers a wide range of papers, well illustrated, from astronomy, physics and geology to zoology and archeology. The volume closes with obituary notices of Dr. Charles D. Walcott by George Otis Smith, and of Dr. William H. Dall by C. Hart Merriam.

Travaux de la Section de Géodésie de l'Union Géodésique et Géophysique Internationale. Vol. V. No. 1. Published by the secretary, Georges Perrier. Paris, 1928 (Rue d'Anjou 78, VIIIE).—This large quarto volume contains the national report of the work carried on in the different countries as presented at the 3d general assembly at Prague on August twenty-ninth to September tenth. There are upwards of thirty of these reports, each fully illustrated by maps or charts. The countries included embrace those of Europe, also others from India, Siam and Japan to Egypt, Canada and the United States.

The Bulletin Géodésique.—The seventeenth number of the Bulletin Géodésique, just received, gives a summary of the above reports; also a summary of the transactions of the Executive Committee and of the various Commissions.

The Carnegie Institution of Washington.—Recent publications of the Carnegie Institution are here listed.

No. 299, vol. IV. Letters of Members of the Continental Congress, January 1 to December 31, 1779; by E. C. BURNETT. Pp. lxvi, 581. (\$5.00, cloth \$5.50.)

No. 384. Cathodo-Luminescence and the luminescence of incandescent solids; by E. L. NICHOLS, H. L. HOWES and D. T. WILBUR. Pp. vii, 350; 176 figs., 80 tables. (\$4.00, \$5.00 cloth).—Discusses (1) the fluorescence and after-glow of solid solutions; (2) the luminescence of such solids when rendered incandescent by contact with a hydrogen flame.

No. 386. San Luis Catalogue of 15,333 Stars for the epoch 1910; by LEWIS BOSS and BENJAMIN BOSS, with assistants. Quarto. Pp. lvii, 307. (\$3.25, \$4.25 cloth).—This volume gives the results of observations of southern stars made by the Department of Meridian Astronomy in 1909, 1910, reduced to the epoch 1910.

No. 387. The Mosquitoes of the Americas; by HARRISON G. DYAR. Pp. iv, 616; 123 pls. (\$5.00, \$6.00 cloth).—Classification and description of all the species of mosquitoes (Culicidae-Culicinae) known from North, Central and South America; contains the descriptive parts of Publication No. 159 (out of print) in condensed form with corrected synonymy, and extended to cover all of South America.

No. 388. Archaeological Investigations in Kamchatka; by WALDEMAR JOCHELSON. Pp. viii, 88; 19 pls., 18 figs. and maps. (\$2.75, \$3.75 cloth).—The results of field work in 1910-1911. No traces of paleolithic man were discovered in Siberia but many skeletal remains of neolithic man were found. The relation of the Siberian tribes to Asiatic people is discussed; also thirteen ancient sites were excavated.

No. 396. Revision of Rowland's preliminary Table of Solar Spectrum Wave-Lengths with an extension to the present limit of the Infra-Red; by C. E. ST. JOHN, with assistants. Quarto. Pp. xxi, 238; 1 graph, tables A to E, and 26 tables. (\$5.00, \$5.50 cloth.) Vol. III. Papers of the Mt. Wilson Observatory.—Rowland's Table was published in 1895 to 1897. It was a remarkably consistent system for the means then available, and has been the world standard for thirty years. In the present volume, the list of wave-lengths has been completed and checked, many new identifications have been entered and those of Rowland reexamined. The new material also includes the classification of many lines according to temperature and pressure in laboratory sources, the intensities of sun-spot lines, etc.

The Carnegie Foundation for the Advancement of Teaching. Bulletin Twenty-one. Present-day Law Schools in the United States and Canada; by ALFRED Z. REED. Pp. xv, 598. New York City (522 Fifth Avenue, copies distributed free on application).—This is the fourth volume on the study of legal education which was begun by the Carnegie Foundation in 1913. The

present investigation is based upon personal visits (just before the war) of every law school in this country. All the Canadian law schools were also visited in 1924. The author finds a serious weakness in our legal education and practice in that it still assumes a unity which no longer exists; the activities of lawyers to-day differing as do those of doctors in the medical profession. Further, less than two-thirds of the law schools are connected with colleges and universities, while they vary widely in financial resources. The time required for the study of law has much increased since 1890, which has led to a corresponding increase in night schools. The elective system is criticized as being carried too far. The Canadian problems are simpler than in this country because of the relative simplicity of Canadian laws and stricter requirements for admission to the bar.

Field Museum of Natural History: Annual Report of the Director, D. C. DAVIES, for the year 1927. Pp. 179-376; pls. XXII to XLI. No. 2 of Vol. VII, Report Series.—The year covered by this report has seen the attendance rise to a total of 1,043,546, the maximum since the Museum was founded by the generosity of Marshall Field. Fourteen halls have been added to the space available for exhibits. Also, the activities of sixteen expeditions abroad, with the home work in various lines, have accomplished much for science and education. Many individual contributions of money have been made; these include a gift by Captain Marshall Field of \$10,000 for zoological work in South America in addition to his annual contribution of \$100,000. The total receipts amount to nearly \$1,669,500. The twenty excellent plates, illustrating as many subjects, add much to the value of the volume.

- *Field Museum and the Child*; by STEPHEN C. SIMMS. Pp. 24; 10 pls. Chicago, 1928.—This pamphlet gives an outline of the important work carried on by the Museum among the school children of Chicago.

Abstract of Theses: Science Series, Vol. V. Ogden Graduate School of Science, University of Chicago. Abstracts submitted for the degree of Doctor of Philosophy, September 1926-June 1927. Pp. xi, 461. Chicago, 1928.—This is the fifth volume of the series. It contains abstracts of the theses of seventy-six authors. The largest number, eighteen, are in chemistry; in physics twelve; in mathematics eleven; botany seven; geology and paleontology six; geography five. Others are in physiology, physiological chemistry and pharmacology, hygiene and bacteriology, home economics, astronomy and astrophysics, zoology, anatomy.

OBITUARY.

DR. THOMAS CHROWDER CHAMBERLIN, professor of geology at the University of Chicago since 1892, died on November fifteenth at the age of eighty-five years. A notice is deferred to a later number.

DR. WILLIAM NORTH RICE, professor of geology at Wesleyan University, Middletown, Conn., died on November thirteenth in his eighty-third year. A notice will appear later.

DR. JOHN A. BOWNOCKER, professor of geology at the Ohio State University and director of the Ohio Geological Survey, died on October 20, at the age of sixty-three years.

DR. CLARENCE WENTWORTH MATHEWS, of the department of horticulture at the University of Kentucky, died on September 2 at the age of sixty-seven years.

DR. CALVIN OLIN ESTERLY, of the Scripps Institution of Oceanography at LaJolla since 1910, died on August 10 at the age of forty-nine years.

DR. EUGEN AMANDUS SCHWARZ, the distinguished German entomologist who came to America in 1873, died in Washington on October 15 at the age of eighty-four years.

DR. GEORGE HARTLEY BRYAN, professor of mathematics in the University College of North Wales until his resignation in 1926, died on October 13 at the age of sixty-four years.

DR. DIARMID NOËL PATON, professor of physiology at the University of Glasgow, died on September 30 at the age of sixty-nine years.

DR. SAMUEL OPPENHEIM, professor of astronomy at the University of Vienna, died on August 15 in his seventy-first year.

DR. PETER P. SUSHKIN, the Russian ornithologist, died on September 17, at the age of sixty-four years.

PUBLICATIONS RECENTLY RECEIVED.

The History of Biology; by Erik Nordenskiöld. New York, 1928. (Alfred A. Knopf, Inc.)

Colloid Symposium Monograph; edited by Harry Boyer Weiser. New York, 1928. Chemical Catalog Co., \$6.50.)

Messen Und Wägen; by Dr. Walter Block. Leipzig, 1928. (Verlag von Otto Spamer, 25 R. M.)

Jahresbericht über die wissenschaftliche Biologie. Band I. By Prof. Dr. Tibor Peterfi. Berlin, 1928. (Verlag von Julius Springer, 69 R. M.)

Das Prinzip der Kleinsten Wirkung von Leibniz bis zur Gegenwart; by Adolf Kneser. Leipzig, 1928. (Verlag von B. G. Teubner, 4 R. M.)

Elementary Practical Physical Chemistry; by Frank Sherwood Taylor. New York, 1928. (Oxford University Press, \$1.25.)

The Laboratory Investigation of Ores. A Symposium, edited by Ernest E. Fairbanks. New York, 1928. (McGraw Hill Book Co., Inc., \$3.50.)

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